NBSIR 78-1562

Interim Performance Criteria for Solar Heating and Cooling Systems in Residential Buildings

Second Edition

Solar Technology Program
Building Economics and Regulatory Technology Division
Center for Building Technology
National Engineering Laboratory
National Bureau of Standards
U.S. Department of Commerce
Washington, D.C. 20234

November 1978

Prepared for

Department of Housing and Urban Development
Division of Energy, Building Technology and Standards
Washington, D.C. 20410

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FOREWORD

These interim performance criteria, developed for the Department of Housing and Urban Development (HUD), are intended for use as a baseline document for criteria and standards for the design, development, technical evaluation and procurement of the solar heating and cooling systems to be used in residential buildings during the solar heating and cooling demonstration program authorized by Public Law 93-409, the "Solar Heating and Cooling Demonstration Act of 1974."

This second edition of the "residential criteria" document, represents the first revision to the "Interim Performance Criteria for Solar Heating and Combined Heating/Cooling Systems and Dwellings" published in January 1975. Its revision draws upon comments received and experience gained in the use of two companion documents, the "Interim Performance Criteria for Solar Heating and Cooling Systems in Commercial Buildings," NBSIR 76-1187 and the "HUD Intermediate Minimum Property Standards Supplement, 1977 Edition, Solar Heating and Domestic Hot Water Systems," 4930.2. Major changes or additions to the criteria and evaluation statements contained in the original document are indicated by vertical lines in the margins. Where an entire section has been significantly changed or reorganized, notation appears at the beginning of the section.

These interim criteria are intended primarily for use in the solar residential demonstration program and as a basis for the preparation of definitive performance criteria in accordance with the requirements of Section 8 of PL 93-409. Current plans of the Department of Energy (DoE) and HUD call for preparation of the definitive performance criteria by December 1979. It is also hoped that they will evolve into definitive performance criteria that can be used to develop provisions for model state and local building codes as well as Federal specifications. Comments related to the usability of this document and suggested modifications are encouraged and should be sent to the following address:

Chief, Solar Technology Program
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SI CONVERSION UNITS

In view of the present accepted practice in this country for building technology, common U.S. units of measurement have been used throughout this document. In recognition of the position of the United States as a signatory to the General Conference of Weights and Measures, which gave official status to the metric SI system of units in 1960, assistance is given to the reader interested in making use of the coherent system of SI units by giving conversion factors applicable to U.S. units used in this document.

Length
- 1 in = 0.0254 meter (exactly)
- 1 ft = 0.3048 meter (exactly)

Area
- 1 in^2 = 6.45 x 10^{-4} $meter^2$
- 1 ft^2 = 0.09290 $meter^2$

Volume
- 1 in^3 = 1.639 x 10^{-5} $meter^3$
- 1 gal (U.S. liquid) = 3.785 x 10^{-3} $meter^3$

Mass
- 1 ounce-mass (avoirdupois) = 2.834 x 10^{-2} kilogram
- 1 pound-mass (avoirdupois) = 0.4536 kilogram

Pressure or Stress (Force/Area)
- 1 inch of mercury (60°F) = 3.377 x 10^3 pascal
- 1 pound-force/$inch^2$(psi) = 6.895 x 10^3 pascal

Energy
- 1 foot-pound-force (ft·lbf) = 1.356 joule
- 1 Btu (International Table) = 1.055 x 10^3 joule
- 1 Kilowatt-hour = 3.600 x 10^6 joule = 3.412 x 10^3 Btu

Power
- 1 watt = 1 x 10^7 erg/second
- 1 Btu/hr = 0.2929 watt

Temperature
- $t_{°C} = 5/9\ (t_{°F} - 32)$

Heat
- 1 Btu·in/h·ft^2·°F = 1.442 x 10^{-1} W/m·K (thermal conductivity)
- 1 Btu/lbm·°F = 4.184 x 10^3 J/kg·K (specific heat)
- 1 langley = 4.184 x 10^4 J/m^2 = 1 cal/cm^2 = 3.69 Btu/ft^2

INTRODUCTION

Background

Public Law 93-409, the "Solar Heating and Cooling Demonstration Act of 1974," provides for "demonstration within a three-year period of the practical use of solar heating technology, and . . . . the development and demonstration within a five-year period of the practical use of combined heating and cooling technology." Under the provisions of the Act, the Department of Housing and Urban Development (HUD) has utilized the services of the NBS to develop this document containing interim performance criteria for the design and evaluation of solar heating and cooling systems to be demonstrated by HUD in residential construction.

Objectives

These interim criteria have the following objectives:

1. To provide designers, manufacturers and evaluators with the technical performance criteria that will be used for the solar heating and cooling demonstration program.

2. To establish technical performance levels that will be used for the evaluation and procurement of systems, subsystems and components* for the solar heating and cooling demonstration program.

3. To provide a basis for the development of more definitive performance criteria at a later date.

Scope

The interim performance criteria given for hardware related items including space heating systems, hot water systems, space cooling systems, or combinations thereof**, and their various subsystems, components, and materials are intended to:

1. establish minimum levels for health and safety that are consistent with those presently established for conventional systems used in residential applications,***

2. ensure that the proposed heating, cooling, and hot water systems, or combinations thereof, are capable of providing levels of performance consistent with those provided by conventional systems used in residential applications,***

3. verify that proposed systems, subsystems, and components are capable of providing their design performance levels, and

4. ascertain that the systems, subsystems, and components are durable, reliable, readily maintainable and generally constructed in accordance with good engineering practice.

The criteria given in this document for dwellings primarily consider aspects of planning and design that are different from conventional buildings by reason of the solar energy systems under consideration. The performance requirements of this document are consistent with the requirements of the HUD MPS 4900.1, "Minimum Property Standards for One and Two Family Dwellings; MPS 4910.1, "Minimum Property Standards for Multi-Family Housing; MPS 4920.1, "Minimum Property Standards for Care-Type Housing, and MPS 4930.2, "Intermediate Minimum Property Standards Supplement for Solar Heating and Domestic Hot Water Systems."

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* Definitions are given in the glossary of this document; see page 98.

** Although not specifically mentioned in PL 93-409, it is recognized in this document that not all cooling systems are combined with heating systems.

*** (i.e., the HUD MPS, and recognized building codes and standards)

The interim performance criteria are intended to be flexible in order to allow freedom of design and encourage innovation in keeping with the intent of Public Law 93-409.

Organization and Format

This interim document is organized on the basis of performance criteria dealing with heating and cooling systems and their integration into buildings.

Performance statement entries are presented in the Requirement, Criterion, Evaluation, and Commentary format. The Requirement is a qualitative statement giving the user need or expectation for the item being addressed. It is a general statement of what the system or its subassemblies shall be able to do. The Criterion is generally a quantitative statement giving the level of performance required to meet the application or expectation for the item being addressed. The one or more criteria associated with each requirement state those considerations which are necessary to meet the requirement. Due to limitations in the state-of-the-art, a quantitative statement is not always contained in each criterion in this document. In addition, quantitative statements have been intentionally omitted in some criteria where these values will be provided by the designer. The Evaluation sets forth the methods of test and/or other information upon which an evaluative judgment of compliance with a criterion will be based. It states the standards, inspection methods, analyses, review procedures, historical documentations, and/or methods which may be used in evaluating whether or not the system and its subassemblies as designed comply with the criterion. It is expected, in many cases, that the review of documentation of in-use performance, or professional judgment, will be used as evaluative tools in lieu of testing. The Commentary provides background for the reader and presents the rationale behind the selection of specific data presented in the Requirement, Criterion, or Evaluation. The commentary is intended for information purposes, and is therefore only advisory.

The document is organized into chapters on the basis of the performance attributes listed below.

1. Thermal performance statements are used to evaluate the ability of systems and their subassemblies to operate and provide their rated output. The ability of the solar heating system to maintain the building at a specified temperature under a given set of outdoor conditions is an example of a thermal consideration.

2. Mechanical performance statements treat the mechanical design and performance of the solar energy systems and their subassemblies. Factors such as the ability of the system to withstand normal design service conditions, e.g. pressure and temperature, are considered under this category.

3. Structural performance statements deal with the ability of systems and subassemblies to maintain their structural integrity under in-service and extreme conditions. Factors such as wind, snow and seismic loads are considered under this category.

4. Safety deals with the mitigation of hazards that could result in property damage, or injury and death. Hazards such as those due to fragile, toxic and/or flammable materials are considered under this category.

5. Durability/Reliability relates to the ability of systems and their subassemblies to perform designed functions for a specified interval under designated use conditions. Corrosion and thermal degradation are typical durability/reliability related items.

6. Operation and Servicing deals with the features of systems and their subassemblies which allow them to be maintained in good operating condition for extended periods of time. Routine scheduled maintenance, corrective maintenance, replacements, and repairs are considered under this category. Accessibility is an important maintainability consideration.

7. Building and Site performance statements deal with the interactions between the solar energy system and its surrounding environment, the building and site. These performance statements provide for integrating the building and site with the system and its components without seriously degrading the environment or impairing the normal function of the building and its components.

For the purposes of this document, the various systems and subsystems, both active and passive, treated in this document are defined as follows:

The heating (H) system is the complete assembly of subsystems and components necessary to convert solar energy into thermal energy and use this energy in combination with auxiliary energy, where required, for space heating purposes.

The cooling (C) system is the complete assembly of subsystems and components necessary to convert solar energy into thermal energy and use this energy in combination with auxiliary energy, where required, for space cooling purposes. (Where cooling is required, nocturnal radiation, evaporative cooling, and/or other means may be used in combination with, or in lieu of, heat actuated space cooling.)

The hot water (HW) system is the complete assembly of subsystems or components necessary to convert solar energy into thermal energy and use this energy in combination with auxiliary energy, where required, to provide hot water in the building. It may either be integrated directly into the H, C, or combined H and C (H/C) system or be completely separate from them. The term hot water as used in this document includes both domestic hot water (DHW) and service hot water (SHW). Service hot water may either be potable or non-potable depending on its intended use.

The term H/C/HW system is used when a requirement or criterion is applicable to the individual H, C, or HW systems or any combination thereof.

The energy transport subsystem includes those portions of the H/C/HW systems which transport energy throughout the systems. Heat transfer from the collector to storage and from storage to the point of use is accomplished through the energy transport subsystem.

The control subsystem comprises all of the devices and their electrical, mechanical, pneumatic or hydraulic auxiliaries used to regulate the processes of collecting, transporting, storing and utilizing energy in response to the thermal, safety and health requirements of the building occupants or building.

The auxiliary energy subsystem utilizes conventional energy sources to back up and/or supplement the output provided by the solar energy system.

The collector subsystem serves the primary function of absorbing solar energy, converting it into useful thermal energy, and transferring the thermal energy to a heat transfer fluid. It consists of the entire collector array, with its one or more collector units, together with associated manifolding and interconnections.

The storage subsystem serves the primary function of storing thermal energy so that it can be used when required. Specific designs may utilize more than one heat storage temperature (e.g. dual temperature storage) and may also employ cold storage in all or part of the storage subsystem.

This document is not final in nature. With the present state-of-the-art, there will be a need for periodic updates to readjust levels of acceptability for both systems and components. A major reason for including a commentary in the presentation is to assure a workable process of updating these interim performance criteria by establishing the basis for selection of performance levels and methods of evaluation so that, when questions arise as to the basis for a particular criterion, the reader will have available the rationale behind the criterion.

TABLE OF CONTENTS

1.1	Requirement	<u>H and C system performance</u>. H, C, and H/C systems shall be capable of collecting solar energy and converting it into useful thermal energy. This thermal energy and auxiliary energy, as required, shall be used to meet the total energy needs for building heating/cooling.
1.1.1	Criterion	<u>Heating design temperatures</u>. The heating system shall be designed and facilities provided to maintain the indoor temperature limits in occupied spaces for 97 1/2 percent winter outdoor design conditions. See chapter 23 reference [1]*, Section 615-3 of references [2, 3, 4], for the geographic area in which the system is to be operated.
	Evaluation	Review of design parameters, HVAC equipment and heat loss calculations. A building load calculation procedure comparable in detail at least to the modified degree-day method shall be used, see reference [1], Chapter 24 and reference [5], Chapter 43. The design load shall be evaluated and used on the same time basis as the solar energy system calculations (i.e., hourly, daily or monthly).
	Commentary	Heating equipment utilizing conventional energy, ambient air, ground heat or stored thermal energy may be used in conjunction with the solar energy system in an assist or auxiliary mode. Passive techniques should be designed to collect, store, or distribute the thermal energy in a controllable manner. Comfort conditions combining the effects of dry bulb temperature, mean radiant temperature and relative humidity are presented in ASHRAE Standard 55-74 [7]. Occupied spaces for sedentary activities in normal dress are usually designed for heating to maintain a recommended indoor temperature of 70°F (21°C) dry bulb [2, 3, 6]; however, mean radiant temperature may be used on an equal basis to calculate comfort conditions. Minimum and maximum temperature and humidity conditions are also specified in ASHRAE Standard 55-74 [7]. Indoor design temperatures have not been specified in this criterion because they vary depending on when and how a space is used. Spaces intended to be used as part of a passive system may be designed for temperature fluctuations compatable with their functional use. Housing for the elderly and care-type facilities may use other indoor design temperatures and design parameters [3, 4]. The design requirements for a building utilizing passive solar energy methods may require a higher level of detailed load analysis. An example of the analysis considerations is presented in ASHRAE Standard 90-75 [6].
1.1.2	Criterion	<u>Cooling design temperature</u>. Where comfort air conditioning is required or used, in occupied spaces, the cooling system shall be designed and facilities provided to maintain the indoor temperature for 2 1/2 percent summer outdoor design conditions. See chapter 23 reference [1], Section 615-5 of references [2, 3, 4] for the geographic area in which the system is to be operated.
	Evaluation	Review of design parameters, HVAC equipment and heat gain calculations. A procedure comparable in detail with the degree-hour method shall be used, see reference [1], Chapter 25, reference [5], Chapter 43. The design load shall be evaluated and used on the same time basis as the solar energy system calculations (i.e., hourly, daily or monthly).

*Numbers in brackets represent references given at the end of each chapter.

Commentary

Air conditioning equipment utilizing conventional energy, ambient air, ground sink, or stored thermal energy may be used in conjunction with the solar system in an assist or auxiliary mode. The use of evaporation, nocturnal radiation, dessication, or other passive techniques should be designed to operate in conjunction with devices which collect, store, or distribute the converted thermal energy in a controllable manner.

Occupied spaces for sedentary activities in normal dress are usually designed for cooling to maintain a recommended indoor temperature of 75°F (24°C) [2, 3, 6]. Minimum and maximum temperatures are also specified in the ASHRAE Standard 55-74 [7]. Indoor design temperatures have not been specified in this criterion because they vary depending on when and how a space is used. Spaces intended to be used as part of a passive system may be designed for temperature fluctuations compatible with their functional use. Buildings with special functional requirements such as care-type facilities and housing for the elderly may use other indoor design temperatures and design parameters [3, 4].

1.1.3 Criterion

Relative humidity. If humidification is provided, it shall be designed and equipment provided to provide a relative humidity of no greater than 30 percent. If dehumidification is provided, it shall be designed to provide a relative humidity of no less than 60 percent.

Evaluation

Review of design parameters and calculations made in accordance with ASHRAE Standard 90-75 [6] to determine if the design relative humidity lies within the comfort envelope defined in ASHRAE Standard 55-74 [7].

Commentary

This criterion recognizes that some solar energy systems may be designed for humidification or dehumidification purposes and that in such cases, the limits established by Section 5 of ASHRAE Standard 90-75 which recognize the energy expenditure required should be used.

Building spaces with special functional requirements may use other relative humidity design conditions. Design procedures have been established to control relative humidity, see reference [1], Chapter 7 and reference [8], Chapter 5. This control should be achieved as much as possible utilizing energy that would otherwise be rejected.

1.1.4 Criterion

Thermal performance. The average yearly contribution of solar energy to the operation of the H, C, and H/C systems shall be specified in the design and shall result in a reduction (or comparative saving) in the average annual consumption of conventional energy for the total building heating/cooling needs.

Evaluation

Review of analytical methods, drawings, test data and calculations. Analytical predictions or correlations based upon measured or simulated performance including the heating and cooling loads, solar subsystem or component performance and the climatic conditions shall be utilized to predict the percentage of average monthly and yearly total energy requirement to be provided by solar energy and auxiliary energy and to determine the operating energy and thermal losses. Hourly or daily input data intervals are required for simulation calculations. Predictions utilizing correlation charts may be based upon monthly average climatic data for sites where at least 10 years of weather data are available.

The prediction of system performance should reflect the cumulative degradation in components resulting from environmental deterioration or system wear.

Commentary — Experimental verification of complete system performance may or may not be practical for residential size systems prior to installation; therefore, analytical simulation methods employing empirical sub-system or component performance can be used to calculate the performance over the full range of operating conditions when measured performance data are not available.

Examples of analytical simulation methods for calculating system performance are described for active systems in references [9, 10, 11, 12, 13, 14, 15, 16] and for passive systems in references [17, 18, 19, 20, 21, 22, 23, 24]. Systems as actually installed may not correspond exactly with predictive models, i.e., ducts that leak, flow restrictions, uninsulated pipe or duct runs, or flow imbalances. Sources of insolation data and data reduction methods are described in references [25, 26, 27, 28, 29]. Performance factor definitions and evaluation procedures are presented in references [30, 31]. Since verification of the correlation of simulated versus actual performance has not been completed, simulation methods used to predict actual performance should be considered with this understanding. It is important to match system components, i.e., collectors, heat exchangers, storage, auxiliary, etc., to building load for efficient performance. In passive systems this will require careful design of storage and control elements to prevent excessive space temperatures and non-collection period heat losses. Such features may include aperture insulation and shading devices.

For passive systems the determination of reduced energy consumption may be based on a comparison with: a) the same building without the solar aperture, or b) a reference building. Reference [31] presents a discussion of these evaluation procedures. Data on actual operation of several passive systems is presented in references [20, 21, 32, 33, 34].

1.2 Requirement — HW system performance. The HW system shall be capable of collecting solar energy and converting it into thermal energy which shall be used in combination with storage, if provided, and auxiliary energy to supply an adequate amount of hot water at an acceptable temperature to meet the needs of the application.

1.2.1 Criterion — Load. Single family and multifamily residential HW systems with individual water heaters shall be capable of providing hot water at a tap temperature of 140°F and with draw and recovery rates as shown in Tables 1A-1 and 1A-2 in Appendix 1. For multifamily housing with central water heating, the domestic water heating capacities shall be based upon ASHRAE design criteria in reference [5], Chapter 37. The minimum daily usage shall be as indicated in Table 1A-3 in Appendix 1. For housing for the elderly and care-type housing, temperatures are specified in Section 615-6.1 of MPS 4910.1 [3] and MPS 4920.1 [4], respectively.

Evaluation — Review of plans, specifications, and calculations. Total energy requirements should be based upon actual use and local water source temperature when known.

Commentary — A residential HW design temperature of 140°F is required by the HUD MPS [2, 3] and is necessary to meet some appliance operating temperatures and varying demand and deterioration in system performance over time. The local source water temperature can vary from 33 to 80°F with climate, region, and season. For guidance, Table 1A-4 of Appendix 1 lists monthly average source water temperature for 14 cities. Tables 1A-1 and 1A-2 of Appendix 1 define overall HW system draw and recovery rates, however, storage size and auxiliary energy input must be determined for the type of solar

system employed. For two tank systems these sizes may be appropriate for one of the tanks while for single tank systems storage requirements are normally larger.

1.2.2	Criterion	Thermal performance. The average yearly contribution of solar energy to the operation of the HW system shall be specified in the design and shall result in a reduction in the average annual consumption of conventional energy for domestic hot water heating.
	Evaluation	Review and analysis of drawings, test data, and calculations. Analytical predictions or correlations based upon measured or simulated performance including at least the source water temperature, hot water requirements, HW system performance, and the climatic conditions shall be utilized to predict the percentage of average monthly and yearly total energy requirements to be provided by solar energy and auxiliary energy from conventional energy sources. Hourly or daily input data intervals are required for simulation calculations. Predictions utilizing correlation charts may be based upon monthly average climatic data for sites where at least 10 year weather data are available.
	Commentary	When available, testing in accordance with proposed ASHRAE Standard 95-P [35] will provide a measure of solar contribution on a standard solar day. Examples of analytical and design methods for active systems are described in references [10, 11, 12, 13, 14, 17, 29, 36, 37]. Thermosyphon system modeling is described in [23]. Since verification of the correlation of simulated vs. actual performance has not been completed, simulated methods used to predict actual performance should be considered with this understanding. TRNSYS computer studies evaluating the influence of (a) single tank vs. double tank configuration, (b) stratified vs. mixed tank performance, and (c) nominal vs. improved insulation on HW system performance is available in references [38 Appendix A, 39]. A further study concerning the effects of stratification is presented in reference [40]. The effectiveness of solar hot water systems is influenced by the correlation between the daily withdrawal schedule and the availability of solar energy. These parameters should be considered during the design when known.
1.3	Requirement	Collector performance. The solar collectors shall absorb solar energy and convert it into useful thermal energy. The collectors shall be capable of dissipating thermal energy (i.e., nocturnal reradiation or excess heat dumping) where this function is included in the design.
1.3.1	Criterion	Thermal performance of component collectors. The solar collectors shall collect or dissipate energy at their design values.
	Evaluation	Review of drawings, calculations, and test data. Solar collector panel performance data shall be generated using the method described in ASHRAE Standard 93-77 [41] or any other comparable method demonstrated to have an overall limit of error of less than ± 5%.
	Commentary	Typical slope intercept curves for flat black and selective coated absorber panels with one and two covers are shown in Figures 1A-1 and 1A-2 in Appendix 1 for liquid heat transfer fluids. Similar data for collectors using air as the heat transfer fluid are shown in Figures 1A-3 in Appendix 1.

The 93-77 standard test method provides the efficiency as a function of inlet temperature, ambient temperature, and insolation for collectors. The collector must have a single heat transfer fluid inlet and outlet and must be separate from the thermal storage device. Collectors with special geometric, optical, or thermal characteristics may require additional data or other tests to fully describe their thermal performance for all environmental and operating conditions. Additional information on collector design, performance, and operation is available [14; 29,Chapter 8; 42; 43; 44]. A method of calculating all day performance has been proposed [45] and thermosyphon collectors are discussed in reference [23, 34].

1.3.2 Criterion — Thermal performance of combined collector-storage units. Combined collectors shall collect or dissipate energy at their design values.

Evaluation — Review of calculations, drawings, and test data.

Commentary — Combined collectors may be active or passive. Consensus methods to calculate or experimentally determine the performance of collectors combined with storage do not currently exist. However, the performance of systems which employ combined collectors can be predicted using analytical methods cited in section 1.1.4 and preliminary procedures or approaches to predicting the performance of mass storage wall collectors (Trombe wall) have been described [32]. Flow resistance, dwell time and auxiliary energy requirements may be significant factors in performance evaluation of active combined collectors. Reference [46] discusses performance of one type of combined collector/storage system.

1.4 Requirement — Thermal storage performance. When included in the design, the storage subsystem shall be capable of providing its rated output under design loads and the required output for all part load conditions during which the solar energy system contributes heat. The storage of thermal energy from sources other than solar may be utilized when feasible.

1.4.1 Criterion — Storage capacity and rate. The storage subsystem shall provide sufficient heat transfer rates and thermal energy capacity to absorb and store energy at the maximum design collection rate.

Evaluation — Review of drawings, calculations, and/or test data
The thermal storage design shall be evaluated using the procedure prescribed in ASHRAE Standard 94-77 [47] or a comparable method demonstrated to have an error of ± 5% or less, where applicable.

In systems where storage cannot be separated analytically from other components, total system performance must be evaluated. Methods for this analysis and evaluation are cited in section 1.1.4. The evaluation of selected passive storage methods has been reported in references [20, 32].

Commentary — Minimum storage capacity for passive solar systems can be as low as 30-45[5] Btu/^{o}F - ft^2 of collector aperture for directly irradiated mass. Indirectly heated storage mass may need to be 4 to 5 times this amount. For active systems, in climate regions with small insolation, it is possible to have a satisfactory solar system with little or no storage but a minimum of 500 Btu/ft^2 if collector is a more usual minimum.

A number of factors are of importance in evaluating thermal storage: adequate thermal capacity, sufficient heat transfer surface and temperature gradients. ASHRAE Standard 94-77 measures the combined effect of heat capacity, heat transfer surface and temperature gradients.

The standard is intended for use with both sensible and latent heat (phase change) type storage media. However, additional tests may be required to evaluate devices employing phase change phenomena.

Adequacy of heat transfer surface area is of concern primarily in air systems and liquid systems employing heat exchange into storage. For air systems, properly sized rock storage normally provides adequate surface area but other materials and configurations such as stacked brick may not. Rock storage comprised of uniformly sized rock provides void space for air passage, turbulence and heat transfer. Rock sizes from 3/4 in. to 1 1/2 in. have been recommended [50] but sizes up to 3 in. have been used.

In passive systems, the total required storage heat transfer capacity is related to the amount of surface area that is directly irradiated by the sun. It is important that directly irradiated surfaces be so designed that they are not insulated from the solar radiation (i.e., avoid rugs, wall hangings, etc.). This relationship is discussed in reference [19]. In addition, the storage mass must have sufficient thermal conductivity from the outside surface to the interior of the storage.

In air systems, pressure drop through storage is an important consideration. Insufficient flow resistance may result in flow short circuiting and consequent loss of heat storage area. Large pressure drops result in excessive operating energy. Dampers which do not seal completely may cause partial bypassing of thermal storage and hence a decrease in storage effectiveness.

Thermal stratification in both liquid and solid type storage devices is generally desirable to improve collector performance. However, stratification in liquid systems may reduce the total heat storage capacity when the system is operated at maximum draw rates.

A discussion of the effects of stratification in liquid systems is presented in references [38 Appendix A, 39, 40].

Thermal storage can be provided for hot or cold applications and at a range of temperature in more than one container. Single vs. multi-tank configurations for HW systems are discussed in reference [38 Appendix A]. The use of thermal storage in conjunction with dampening of time and weather dependent loads on machines, electrical peak shaving, and heat recovery should be considered.

1.4.2 Criterion

Thermal losses. Thermal losses for the storage subsystem shall not exceed the design values throughout the operating range for the storage location and ambient temperature environment.

Evaluation

Review of drawings, calculations, and/or test data. Thermal losses shall be evaluated using the procedures described in ASHRAE Standard 94-77 [47] or a comparable method demonstrated to have an error of $\pm$ 5% or less, where applicable.

Commentary

Use of test methods such as ASHRAE 94-77 will give a measure of thermal losses under operating conditions. This is of particular concern with air systems when leakage may be difficult to detect and significantly reduced systems performance may result. Also, reverse thermosyphoning from storage to collector during non-collection periods can lead to significant thermal losses. Design configuration and/or check valves and dampers can reduce such losses.

Criteria for thermal losses from liquid storage tanks and piping are presented in ASHRAE Standard 90-75 [6]. Insulation greater than these levels is desirable as loss from storage can greatly deteriorate system performance. The effect of losses in HW systems is discussed in reference [38 Appendix A]. Thermal energy lost within the building envelope during the heating season may be credited to the solar energy system. Conversely, thermal losses during the cooling season must be considered in the design as adding to the cooling load.

Thermal energy losses from storage devices used solely for solar HW thermal storage should be charged to the solar energy system. Thermal losses from storage tanks used as part of the conventional HW heating should be charged to the auxiliary heating system.

Care should be given to assure the continued effectiveness of insulation, particularly that located in exterior and underground locations where the presence of water may lead to the soaking of insulation which will result in thermal losses. Mechanical strength of thermal insulation is also a concern. When movable insulation is used, as in passive systems, design consideration shall be given to potential structural damage. The compressive strength of insulation used underneath storage vessels is most important as crushing of insulation will reduce its thermal effectiveness. Mechanical strength is also important in avoiding sagging, pulling away from components and opening up at seams.

1.5 Requirement

Component/system/space interactions. The presence of system components shall not significantly affect the efficient operation of the H/C/HW systems or the habitability of the occupied spaces.

1.5.1 Criterion

Heat or humidity transfer effects. Heat or humidity transfer from the collector, thermal storage, piping, or other elements shall not interfere with the efficient operation of the H/C/HW systems or cause loss of control of temperature, humidity, or other controlled conditions in occupied spaces.

Evaluation

Review of drawings, specifications, calculations, and test data for compliance with the requirements of section 1.1. A thermal analysis including calculations of the heat transfer and condensation rates from storage containers, piping, and other thermally insulated components or test data on equivalent material and configurations may be necessary in designs where prior experience does not exist. In passive systems, calculations of over-heat under heat, and frequency of temperature swing should be reviewed.

Commentary

It is realized that some heat transfer from insulated piping, ducting, and storage containers will occur within or under a building structure. Over-heating and condensation can create adverse conditions.

In direct gain passive systems in particular, excessive heat build up may occur. This is often most severe during spring and fall.

1.6 Requirement

Energy transport performance. The energy transport subsystem shall transfer the required thermal energy between the operating subsystems at or above the design efficiency under full load conditions.

1.6.1 Criterion

Energy Distribution. In spaces heated or cooled using natural energy distribution by radiation, convection, conduction and evaporation,distribution shall be at rates and in locations needed to meet design system operating requirements.

	Evaluation	Review of drawings, specification, calculations and test data.
	Commentary	The intent of this criterion is to recognize the need to carefully study the means and paths of energy distribution in passive systems. Such study should consider surfaces directly and indirectly heated by the sun, paths of air movement and the variation in these on both a daily and yearly cycle.
1.6.2	Criterion	<u>Thermal losses</u>. Thermal losses, including air leaks, for the energy transport subsystem shall not exceed the design values throughout the operating range and ambient environment conditions.
	Evaluation	Review of drawings, specifications, calculations, and test data.
	Commentary	Criteria for thermal losses in piping and ducts are presented in ASHRAE Standard 90-75 [6]. Insulation greater than these levels is desirable as thermal losses can greatly deteriorate system performance. Variations in the thermal conductivity, specific heat, and viscosity of the heat transfer medium with temperature should be considered in the design, where applicable. Design data and analytical procedures for thermal insulation and heat transfer in building systems are available in the literature [1, 6, 48]. Thermal energy losses from piping or ducts associated with the solar energy system within the building envelope during the heating season may be credited to the solar energy system. Conversely, thermal losses during the cooling season must be considered in the design as adding to the cooling load. Pre-formed insulating materials for pipes and round ducts and molded coverings for bends, elbows and other fittings will help to reduce crushing in installation.
1.6.3	Criterion	<u>Electrical operating energy</u>. The use of electrical operating energy for the energy transport subsystem shall not exceed the design values throughout the operating range.
	Evaluation	Review of drawings, specifications, calculations, and test data.
	Commentary	The electrical operating energy required for fans, pumps, controls, dampers, or valves can significantly influence the overall system efficiency. These energy requirements should be accounted for in the evaluation of the individual solar energy system and the H/C distribution system. Operating energy for ancillary functions such as freeze protection, excess heat dumping, and automatically operated shades, shelters, drapes, louvers, or other mechanized controls should be included.
1.7	Requirement	<u>Control system performance</u>. The control subsystem shall provide for the safe and proper operation of the H/C/HW systems.
	Commentary	Requirements for system performance monitoring are given in section 6.4.

1.7.1 Criterion		Control of energy utilization. The control subsystem shall be designed, and components provided, to control the flow of energy as specified in the system design.
	Evaluation	Review of schematic diagrams depicting the control subsystem and their function during each operational mode.
	Commentary	Each control mode shall be clearly defined in terms of sensor type and location, control device or activator location and position, set points or control value and heat transfer fluid flow direction if applicable. Typical system control modes include collector-to-storage, storage-to-load and collector protection from overheating or freezing. A variety of methods may be used to prevent freezing if a freeze tolerant design is not used. These methods are discussed in 2.1.17. Control priority should be given to modes which use the least auxiliary energy. Draw from solar supply first then utilize other modes based on their auxiliary energy consumption.

1.7.1 Criterion — Control of energy utilization. The control subsystem shall be designed, and components provided, to control the flow of energy as specified in the system design.

Evaluation — Review of schematic diagrams depicting the control subsystem and their function during each operational mode.

Commentary — Each control mode shall be clearly defined in terms of sensor type and location, control device or activator location and position, set points or control value and heat transfer fluid flow direction if applicable. Typical system control modes include collector-to-storage, storage-to-load and collector protection from overheating or freezing. A variety of methods may be used to prevent freezing if a freeze tolerant design is not used. These methods are discussed in 2.1.17. Control priority should be given to modes which use the least auxiliary energy. Draw from solar supply first then utilize other modes based on their auxiliary energy consumption.

1.7.2 Criterion — Circulation control. In the collector to storage/load loop, control shall be designed to provide, when in the heating mode, for the circulation of heat transfer fluid only when useful energy can be collected.

Evaluation — Review of drawings and specifications.

Commentary — Circulation in liquid systems is typically limited to conditions when the absorber plate temperature is about 10°F higher than the storage or load use temperature to minimize circulation cycling. A larger temperature differential may be used for air systems depending upon the circulating fan electrical power requirements. In a liquid thermosyphon system, if thermal storage is not elevated about 18 inches above the top of the collector, controls may be necessary to stop reverse flow. Sensor locations are normally near the collector outlet and in the lower portion of the storage tank. Control requirements for various system types are discussed in reference [29].

1.7.3 Criterion — Manual adjustment. If manual control adjustments are required during normal operation of the solar system, the control subsystem shall be designed to ensure that the safety of the system and the building in which it is installed are not compromised by failure to make these manual control adjustments.

Evaluation — Review of drawings, specifications, and operating procedures.

Commentary — The intent of this criterion is to assure that damage to the system or building due to freeze-up or overheating will not occur if routine procedures are not completed during periods of occupant absence. Further coverage of freeze protection is given in section 1.8. These provisions are not intended to restrict appropriate seasonal shutdown manual controls. Control considerations for solar H and C applications [14] and for HVAC equipment in general are discussed in references [5, 8, 49].

Systems may require various degrees of attention for periodic adjustments. The use of main valves and duct dampers with visual position indicating devices is encouraged.

1.7.4 Criterion — Inhabited space temperature control. Each H, C, or H/C system shall be capable of providing occupied space temperature regulation by at least one adjustable control or combination of controls and sensors capable of control within the range from 55°F to 85°F.

Evaluation — Review of drawings and specifications.

Commentary — Designs should allow for summer ventilation with preference given to natural ventilation over mechancial methods. Controls may be automatic or manual.

In certain multizone or multisystem applications, a priority control may be needed to avoid simulataneous heating and cooling of a common conditioned space. Localized controls for building heating and cooling are discussed in reference [5].

1.7.5 Criterion — Hot water temperature. The temperature control for the auxiliary energy source shall be capable of adjustment over the range of temperatures acceptable for the intended use.

Evaluation — Review of drawings and specifications.

Commentary — DHW tanks are typically equipped with a thermostat capable of controlling heating over the temperature range of 120°-160°F. Temperature control devices used with solar energy heated storage tanks must be compatible with safety requirements and may require the capability to cool the discharged water as well as heat it (see Criterion 4.2.3).

1.8 Requirement — Auxiliary energy. Auxiliary energy subsystems shall be integrated into the H/C/HW systems to the extent necessary to provide the designed heating, cooling, and hot water. If auxiliary energy control is not automatic, provisions shall be made to insure building freeze protection during unoccupied periods.

Commentary — Compatability of auxiliary energy with the solar system is critical to efficient overall system operation. Methods for sizing auxiliary systems are described in references [5, 6, 49].

Proper integration of auxiliary with the solar system also requires consideration. In heating and cooling systems it is important to be able to isolate auxiliary from the solar side of the system so that auxiliary energy is only used to condition the building. Normally, it is undesirable to have auxiliary energy added into storage as it will reduce collector efficiency. In HW systems, electric auxiliary energy may be used in single tank configurations if stratification can be preserved. In such cases collector efficiency can be maintained with a simple system. In HW systems with gas or oil auxiliary it is normal to use a two tank configuration because stratification is difficult to preserve in the auxiliary tank.

With absorption chillers it has been found to be less energy conserving to have an electric boiler as back up to the solar system, rather than a conventional vapor/compression machine.

1.8.1 Criterion		Design heat loads. The auxiliary energy subsystem shall be designed to meet the peak heating and hot water loads as specified in Criteria 1.1.1 and 1.2.1.
	Evaluation	Review of plans, specifications, calculations, and test methods.
	Commentary	The purpose of this criterion is to recognize the need for 100 percent back up operating capability with the auxiliary energy subsystem when energy derived from solar radiation is not available. Design heat loads are discussed by ASHRAE [1, 5, 6].
1.8.2 Criterion		Design cooling load. The portion of the yearly total (latent and sensible) cooling load provided by the auxiliary energy subsystem shall not exceed the design values specified in Criteria 1.1.2 and 1.1.3.
	Evaluation	Review of drawings, specifications, calculations, and test data.
	Commentary	The design of the cooling system must carefully consider the type and amount of auxiliary energy used to ensure that a saving in conventional energy is realized with the solar cooling system. The use of solar energy should not compromise ventilation of the building.

References 1

1. ASHRAE Handbook of Fundamentals, 1977.*

2. HUD Minimum Property Standards, One and Two Family Dwellings, (No. 4900.1), U.S. Department of Housing and Urban Development, Washington, DC (1973, revised 1976).+

3. HUD Minimum Property Standards, Multifamily Housing, (No. 4910.1), U.S. Department of Housing and Urban Development, Washington, DC (1973, revised 1976).+

4. HUD Minimum Property Standards, Care-Type Housing, (No. 4920.1), U.S. Department of Housing and Urban Development, Washington, DC (1973, revised 1976).+

5. ASHRAE Handbook/Systems, 1976.*

6. ASHRAE Standard 90-75, Energy Conservation in New Building Design, 1975.*

7. ASHRAE Standard 55-74, Thermal Environmental Conditions for Human Occupancy, 1974.*

8. ASHRAE Handbook/Equipment, 1975.*

9. Duffie, J. A. and Beckman, W. A., Solar Energy Thermal Process, John Wiley and Sons, New York, NY, 1974.

10. Beckman, W. A., Klein, S. A. and Duffie, J. A., Solar Heating Design - By the F-Chart Method, Wiley-Interscience Publication, John Wiley and Sons, New York, NY, 1977.

11. F-Chart Computer Program Version 2.3, Solar Engineering Laboratory, University of Wisconsin, Madison, WI.

12. Klein, S. A., et. al., TRNSYS - A Transient Simulation Program, Users Manual, Report 38, Engineering Experiment Station, University of Wisconsin, Madison, WI, 1977.

13. SOLCOST, Solar Energy Design Program for Non-Thermal Specialists, Users Guide for CYBERNET, December 1977, Martin Marietta Aerospace, Denver Division, P.O. Box 179, Denver, CO.

14. Extended Abstracts, International Solar Energy Congress and Exposition (ISEC&E), Los Angeles, CA, July 1975.

15. Proceedings of 1976 Annual Conference, American Section, International Solar Energy Society, Winnipeg, Canada, August 1976, Volume 3, Solar Heating and Cooling of Buildings.**

16. Proceedings of 1977 Annual Meeting, American Section, International Solar Energy Society, Orlando, FL, Volume 1, Solar Collectors and Heating and Cooling Systems.**

17. Passive Solar Heating and Cooling, Conference and Workshop Proceedings, Albuquerque, NM, May 1976, Report No. LA-6637-C, Los Alamos Scientific Laboratory, Los Alamos, NM 87545.

18. Second National Passive Solar Conference, Proceedings, Philadelphia, PA, March 1978.**

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*American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 345 East 47th Street, New York, NY 10017.

+Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402.

++National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

**American Section, International Solar Energy Society, P.O. Box 1416, Kileen, TX 76541.

19. Balcomb, J. D., Hedstrom, J. C. and McFarland, R. D., Passive Solar Heating of Buildings - Preliminary Results, Report No. LA-UR-77-1162, Los Alamos Scientific Laboratory, Los Alamos, NM 87544.

20. Stromberg, R. P. and Woodall, S. O., Passive Solar Buildings: A Compilation of Data and Results, Sandia Laboratories, SAND 77-1204, Albuquerque, NM, August 1977.++

21. "Research Evaluation of a System of Natural Air Conditioning," (Water-mass roof system), California Polytechnic State University, January 1975, HUD Contract No. H 2026 R.

22. Arumi, F. N., "Thermal Inertia in Architectural Walls," Report sponsored by Department of Energy and the National Concrete Masonry Association, NCMA, McLean, VA, 1977.

23. Baughn, J. W. and Dougherty, D. A., "Experimental Investigation and Computer Modeling of Solar Natural Circulation System," Proceedings of the 1977 American Section of ISES Annual Meeting, Orlando, FL.

24. Request for Grant Application, H-8600, Passive Solar Residential Design Competition and Demonstration, Division of Energy, Building Technology and Standards, PD&R, Department of Housing and Urban Development, Washington, D.C. 20410, May 1978.

25. Liu, B. Y. H. and Jordan, R. C., "Availability of Solar Energy for Flat-Plate Solar Heat Collectors," Chapter 1, Low Temperature Engineering Application of Solar Energy, 1967 (Revised edition in reference 29).*

26. Bennett, I., "Monthly Maps on Mean Daily Insolation for the United States," Solar Energy, Volume 9, p. 145, 1965.

27. Climatic Atlas of the United States, National Oceanic and Atmospheric Administration, National Climatic Center, Federal Building, Asheville, NC 28801, June 1968.

28. Climatological Data - National Summary, Published monthly, National Oceanic and Atmospheric Administration, National Climatic Center, Federal Building, Asheville, NC 28801.

29. ASHRAE Applications of Solar Energy for Heating and Cooling of Buildings, 1977, GRP 170.*

30. Streed, E., McCabe, M., Waksman, D., Hebrank, J., and Richtmyer, T., Thermal Data Requirements and Performance Evaluation Procedures for the National Solar Heating and Cooling Demonstration Program, NBSIR 76-1137, August 1976, National Bureau of Standards, Washington, D.C. 20234

31. Ducas, W., Streed, E. R., Holton, J. K. and Angel, W., "Thermal Data Requirements and Performance Evaluation Procedures for Passive Buildings," Second National Passive Solar Conference, Proceedings, Philadelphia, PA, March 1978.

32. Trombe, F., Robert, J. F., Cabanot, M. and Sesolis, B., "Concrete Walls to Collect and Hold Heat," Solar Age, August 1977.

33. Ohanessian, P. and Charters, W. S., "Thermal Simulation of a Passive Solar House Using a Trombe-Michel Wall Structure," Solar Energy, Volume 20, p. 275, 1978.

34. Buckley, S., et. al., "Thermic Diode Solar Panels for Space Heating," Solar Energy, Volume 20, p. 495. ISES Solar Energy, Other papers published in Second National Passive Solar Conference, Proceedings, Philadelphia, PA, March 1978.**

35. ASHRAE Standard 95-P, Method of Testing to Determine the Thermal Performance of Solar Domestic Hot Water Systems.* (In preparation)

36. Gutierrex, G., Hincapie, F., Duffie, J. A. and Beckman, W. A., "Simulation of Forced Circulation Water Heaters; Effects of Auxiliary Energy Supply, Load Type and Storage Capactiy," Solar Energy, Volume 15, pp. 287-298, 1974.**

37. Chinnery, D. N. W., Solar Water Heating in South Africa, NBRI Bulletin 44, Council for Scientific and Industrial Research Report 248, pp. 1-79, UDC 694, 4.551.521.1 (680), Pretoria, South Africa, 1967.

38. Intermediate Standards for Solar Domestic Hot Water Systems/HUD Initiative, NBSIR 77-1272, Prepared for HUD, Washington, DC, 1977.

39. Liu, S. I., Shik, K. and Wood B. D., "Experimental Validation of the Solar Simulation Program TRNSYS for a Solar Domestic Hot Water Heating System," Proceedings of Systems Simulation and Economic Analysis for Solar Heating and Cooling Conference, San Diego, CA, June 1978.

40. Lavan, Z. and Thompson, J., "Experimental Study of Thermally Stratified Hot Water Storage Tanks," Solar Energy, Volume 19, p. 519, 1977.**

41. ASHRAE Standard 93-77, Methods of Testing to Determine the Thermal Performance of Solar Collectors.*

42. Hill, J. E., Streed, E. R., Kelly, G. E., Geist, J. C. and Kusuda, T., Development of Proposed Standards for Testing Solar Collectors and Thermal Storage Devices, NBS Technical Note 899, February 1976, Catalog No. C13.46:899.+

43. Workshop on Solar Collectors for Heating and Cooling of Buildings, Proceedings, National Science Foundation, NSF/RA-N-75-019, May 1975.+

44. 1977 Flat Plate Solar Collector Conference, Proceedings, Orlando, FL, March 1977, Florida Solar Energy Center, Cape Canaveral, FL, FSEC-77-8.

45. Waksman, D., Streed, E. R., Reichard, T. W. and Cattaneo, L. E., Provisional Flat Plate Solar Collector Testing Procedures: First Revision, NBSIR 78-1305A, June 1978, National Bureau of Standards, Washington, DC 20234.

46. Jones, D. E., "System Performance Measurements for a Packaged Solar Space Heating System Equipped with Air-Heating Collectors," Conference on Performance Monitoring Techniques for Evaluation of Solar Heating and Cooling Systems, Washington, DC, April 1978, Organized by the University of Utah, Mechanical Engineering Department, Salt Lake City, UT.

47. ASHRAE Standard 94-77, Methods of Testing Thermal Storage Devices Based on Thermal Performance.*

48. HUD Intermediate Minimum Property Standards Supplement, 1977 Edition, Solar Heating and Domestic Hot Water Systems, (No. 4930.2), U.S. Department of Housing and Urban Development, Washington, DC, 1977.+

49. ASHRAE Handbook/Applications, 1974.*

50. Heating and Air Conditioning Systems Installation Standards for One and Two Family Dwellings and Multifamily Housing Including Solar, SMACNA, 1977.

2.1	Requirements	Functional design. The H/C/HW system shall be designed to be capable of functioning under in-service flow rates, pressures and temperatures, and other mechanical stresses.
	Commentary	A broad scope discussion of problems frequently encountered in design, construction and operation of solar systems is presented in reference [1].
2.1.1	Criterion	Equipment capabilities & applicable standards. Pumps, fans, or other components shall be sized to move the heat transfer fluid through the collector, piping, and/or ducts at design flow rates. All mechanical components shall conform to applicable local and nationally recognized codes and standards.
	Evaluation	Review of drawings, specifications, historical performance, previous test data, and design calculations. Systems or applications that do not lend themselves to engineering analysis may require prototype tests to demonstrate compliance.
	Commentary	In order to transfer heat through the system/subsystem, a number of different transfer approaches such as gravity circulation, combined forced and gravity circulation, or forced circulation may be used.
2.1.2	Criterion	Erosion-corrosion. Liquid piping and associated fittings shall be sized to carry the heat transfer liquid at design flow rates without excessive erosion-corrosion.
	Evaluation	Review of drawings, specifications, historical performance, previous test data, and design calculations.
	Commentary	Reference [2] provides recognized design practices for the determination of limiting velocities for heat transfer liquids. Chapter 36 of reference [3] also addresses this subject.
2.1.3	Criterion	Operating conditions. Collectors, space heaters, water heaters, pumps, valves, regulating orifices, pressure regulators, heat exchangers, and other fluid handling components shall be capable of being operated over the pressure and temperature ranges anticipated in actual service without breakage, rupture, binding, galling, or significant loss or gain in pressure that could impair their intended function.
	Evaluation	Review of drawings, specifications, historical performance, previous test data, and design calculations. Systems or components that do not lend themselves to engineering analysis shall be tested at the maximum and minimum service temperatures with anticipated fluid pressures. To show compliance with this criterion, it is desirable that the design consist of components that are covered by recognized standards, where available, and are specified by the manufacturer to be suitable for the pressure, temperature, and flow application. Provisional tests described in test methods 7.1 (thermal performance), 7.2 (no-flow 30 day degradation), 7.6 (thermal cycling), 7.11 (air collector rupture and collapse), and 7.12 (static pressure leakage test) of NBSIR 78-1305A [4] are one means of assessing the effects of these conditions on collectors.
	Commentary	Available codes and standards are listed by ASHRAE [5].

2.1.4 Criterion

Fluid flow in collectors. When an array of collectors is connected by manifolds, provision shall be incorporated in the manifolds and/or collectors to maintain the design flow rate of the heat transfer fluid through each collector.

Evaluation

Review of drawings, specifications, historical performance, previous test data, and design calculations or testing to determine that each collector will receive its design flow rate.

Commentary

Because of friction and variation in velocity head in manifolding, flow rates may be inadequate through collectors remote from the pump, blowers, or other fluid supply source. This can result in inefficient collector operation. The provision of flow regulating devices is one means of correcting for this problem. Another method is the use of reversed supply and return headers for parallel arrays of collectors with graduated header sizes to compensate for changes in flow rate [6]. Such reverse return methods may not always be capable of coping with varying field conditions and balancing valves, dampers or restrictors may be essential.

Consideration should be given to the effect of header arrangement on collector array temperature rise.

Procedures for flow balancing of air system are presented in reference [4].

2.1.5 Criterion

Entrapped air. When liquid heat transfer fluids are used, the system shall provide suitable means for air or gas removal from high points in the piping system.

Evaluation

Review of drawings and specifications.

Commentary

Except for expansion tanks and air chambers where trapped air is required, trapped air in piping systems and collectors can impede the flow of liquids through piping, reduce heat transfer potential and otherwise reduce overall system efficiency. The freezing of exposed air vent fittings has been known to occur and create trapped air conditions in solar piping systems. The potential buildup of vapor which could create air pockets and thus block or restrict the flow of heat transfer fluids should be considered.

2.1.6 Criterion

Thermal expansion of fluids. Adequate provisions for the thermal expansion of heat transfer fluids and thermal storage fluids that can occur over the service temperature range shall be incorporated into the system design. Expansion tanks shall be sized in accordance with the recommendations of ASHRAE.

Evaluation

Review of drawings, specifications, and design calculations.

Commentary

Water expands about 4 percent in volume when heated from 40°F to 200°F. Other heat transfer fluids will have different coefficients of volume expansion. Means should be provided in the system design to contain this additional fluid volume without exceeding the operating pressure of the system or resulting in spillage.

2.1.7 Criterion

Piping design. Pressure drops shall not exceed the limits specified in the design. Pipe sizing shall be in accordance with recognized methods.

Evaluation

Review of drawings, specifications, and design calculations.

Commentary

Since the energy requirements of pumps are a function of the system flow resistance, pressure drops should be kept as low as practical. The unnecessary use of fittings such as bends, tees, globe valves, reducers, or obstructions to flow should be avoided by careful arrangement of piping runs. Accepted practices for plumbing design are discussed in standard plumbing guides [8, 9]. It is possible to design solar energy systems that consume more conventional energy than the systems that they replace because of high operating power requirements.

A thermosyphon water heating system is an example where pipe sizing for minimum pressure drop is essential as hot water circulation results from the change in density of the fluid with temperature and the movement of a heat transfer fluid by natural convection is achieved by relatively low pressure differentials. Design considerations and equipment performance data is available [10, 11. 12].

2.1.8 Criterion

Duct design. Design of all air heating and air conditioning systems shall be in accordance with applicable recommendations of ASHRAE Chapter 25 [8], the National Environment Systems Contractors Association (NESCA) [9], the Air-Conditioning and Refrigeration Institute (ARI) [13], and/or Sheet Metal and Air-Conditioning Contractors National Association (SMACNA) [12]. Installation shall comply with National Fire Protection Association (NFPA) standards 90B, 31 and 54 [14].

Evaluation

Review of plans and specifications.

Commentary

Duct work should be designed for the shortest practical run and elbows should be kept to a minimum. Unnecessary constructions should be avoided. The use of turning vanes should be considered at duct bends to reduce pressure losses. Low leakage dampers should be selected and dampers should have position indicators to aid in monitoring the system.

Equal pressure loss in the collectors and storage is usually recommended. The addition of ducts, filters, heat exchangers and other appurtenances will establish the total pressure loss which should be kept to a minimum in order to reduce blower operating cost. Blowers sized near the center of their performance curves will allow for minor variations without replacement; however, sizing shall also consider efficiency of operation. Standards for design, sizing, construction and installation of ducts used with solar energy systems are covered in sections 3 and 7 of reference [12].

2.1.9 Criterion

Exhaust and vent openings. Air discharge openings through roofs or exterior walls shall not be located such that their exhaust will cause the deposition of grease, lint, condensation, or other deleterious materials on solar optical components. Similarly, solar components shall not interfere significantly, either physically or aerodynamically, with building vents, flues, and exhausts.

Evaluation

Review of plans and specifications.

Commentary

The wind conditions created around chimneys, flues, plumbing vents, mechanical exhausts and condensers by the presence of solar components should be examined for possible interference with the mechanical operation of such elements. Flues and vents should be located either far enough from higher elements (such as roof mounted solar equipment) or extended far enough above them to insure continuous outward flow from the flue or vent.

2.1.10 Criterion

Thermosyphoning losses. Means shall be provided to prevent undesired loss of thermal energy from storage through thermosyphoning action.

Evaluation

Review of drawings and specifications.

Commentary

Significant losses of energy from storage can occur through this mechanism. System geometry, back draft dampers and check valves are some of the means used to prevent thermosyphoning. Some designs may use thermosyphoning of energy from storage as a means of protection from freezing.

2.1.11 Criterion

Sound and vibration control. Piping, air ducts, and associated fittings shall be designed to carry the heat transfer fluid at design flow rates without excessive noise or vibrations which could induce mechanical stress levels high enough to cause damage.

Pumps, fans, and compressors or other components involving moving parts shall be balanced and/or mounted in a manner such that during start-up operation or shutdown they do not induce excessive noise or vibration that could cause damage.

Design practices to control sound and vibration shall be in accordance with the applicable recommendations of ASHRAE [3, 8], NESCA [9], ARI [13], and/or SMACNA [12].

Evaluation

Review the drawings and specifications, conduct a prototype inspection, and make sound and vibration measurements if deemed necessary. Sound and vibration measurements, if required, shall be made in accordance with the applicable recommendations of ASHRAE, as stipulated in Chapters 35 and 40 of reference [3].

Commentary

Examples of possible sound and vibration are: a) lengths of piping and connecting equipment that are resonant with pressure pulsation frequency; b) vibration resulting from motors, pumps, fans, and compressors which are not properly mounted; c) water hammer and quick closing valves; d) wind excitation of piping by turbulence or vortex shedding; and e) ducting with excessive air velocities.

2.1.12 Criterion

Water hammer. When a liquid is used as the transfer fluid and quick closing valves are employed in the design, the piping system shall be able to control or withstand potential "water hammer". Water hammer arresters shall be in compliance with applicable codes.

Evaluation

Review of drawings, specifications, and/or design calculations.

Commentary

Pressure rises resulting from water hammer may damage piping and equipment. It can be minimized by piping system design, or the use of water hammer arresters [15].

2.1.13 Criterion

Vacuum relief protection. Closed storage tanks and piping located at elevations above the system served shall be protected against collapsing pressure if subjected to vacuum. Such components shall be designed to withstand such pressures or have vacuum relief protection.

Evaluation

Review of drawings and specifications.

Commentary

Possible collapse of large diameter tanks and piping from atmospheric pressure is an important design consideration [16].

2.1.14 Criterion — <u>Thermal changes</u>. The system components and assemblies shall be designed to allow for the thermal contraction and expansion that will occur over the service temperature range.

Evaluation — Review of drawings, specifications, and calculations.

Commentary — Piping and other components may experience changes in dimensions as a result of temperature changes. Such changes can result in excessive stresses within the piping, piping supports, structure, pumps, compressors, and solar collectors if means are not incorporated in the piping system design to allow for the thermal movement. These problems are especially severe in long runs and with intersecting lines. Movement due to thermal changes can also result in inadvertent dissimilar metals contact with other components and building elements, leading to corrosion problems.

2.1.15 Criterion — <u>Pipe and duct hangers</u>. Pipe and duct hangers used to support insulated pipes or ducts shall be designed to avoid damaging the insulation material.

Evaluation — Review of drawings and specifications.

Commentary — If pipe or duct hangers are installed over the insulation material, sleeves or plates should be used to avoid damaging the insulation. Care should also be taken that dielectric insulation of dissimilar metals is not broken. Hangers must provide adequate support and correct pitch of pipes to avoid liquids pockets remaining during drain down conditions.

2.1.16 Criterion — <u>Flexible joints</u>. All systems employing heat transfer fluids shall be designed to be capable of accommodating flexing of plumbing and fittings.

Evaluation — Review of drawings and specifications.

2.1.17 Criterion — <u>Freezing protection</u>. System components including heat transfer liquids shall be protected from damage by freezing at the lowest ambient temperatures that will be encountered in actual use.

Evaluation — Review of drawings and specifications.

Commentary — The intent of this criterion is to insure that rupture or other damage to solar collectors and associated piping and equipment will not occur from expansion of water if it freezes. In air systems, damper leakage can freeze water in air-to-water heat exchangers. The intent of this criterion is not to restrict the designer to the use of antifreeze solutions for liquid systems.

If automatic drain down is the freeze protection technique to be used, automatic air vents, vacuum relief valves and drain down valves should be protected from freezing. Rate of drain down should be compared to rate of thermal losses so that ice blockages will not form. Drain down systems are frequently designed to drain at an outdoor temperature of about 38°F because of subcooling by radiation losses and to refill at about 42°F to minimize cycling. Such set points may be used but with the penalty of not collecting useful energy when solar radiation is available at the time of cold ambient temperatures. With drain down systems, flow rates with and without siphon return will have to be considered in order to maintain flow rates through collectors to manufacturers' recommendations. Both the oversizing of return lines to avoid siphon formation or the use of restrictors to insure it are ways to control flow.

The circulation of antifreeze heat transfer fluids at freezing temperatures because of thermosyphoning, control or pump malfunction may lead to freezing of domestic hot water at the heat exchanger interface.

Fail safe freeze protection methods are desirable since in the event of power failure, freeze protection methods which require electric power will be ineffective. Systems employing drain down require control provisions to provide venting for draining and refill and may require special provisions to prevent contamination or corrosion of the heat transfer system during these operations (see Criterion 2.1.10).

Continuous circulation of heat transfer fluid should not be used for freeze protection due to the excessive energy loss this causes. Pulse circulation may be justified in very moderate climates where freezing temperatures are infrequent. In addition, only in such warm climates can the use of electrical heating tapes or elements be justified.

Designs which utilize vacuum insulation for protection can freeze if this vacuum is lost due to leakage or for other reasons. Freeze tolerant designs should be tested for reliability.

Other considerations of freeze protection are presented in sections 5.1.2 and 5.1.3.

A provisional test for evaluating the freeze resistance of solar collectors under in-use conditions is described in test method 7.6 given in NBSIR 78-1305A [4].

2.2 Requirement — Leakage prevention. Subsystem assemblies containing heat transfer fluids shall not leak to an extent greater than specified in the design when operated at all conditions within the design operating range.

2.2.1 Criterion — Leak testing: liquid systems. Those portions of installed H/C/HW systems which contain pressurized liquid heat transfer fluids and are not directly connected to the potable water supply shall not leak when pressures of not less than 1-1/2 times their design pressure are imposed for a minimum of 15 minutes. Those portions of the system designed to operate at atmospheric pressure shall be filled with the heat transfer fluid and shall not leak when filled for a minimum of 30 minutes.

Evaluation — Review of specifications and testing. The test pressure shall be applied for a period of time necessary to inspect each joint for leakage. The temperature of the water shall be within 5°F of the ambient atmosphere. A pressure gauge should be observed for this period to determine whether the pressure drop is within allowable limits. Provisional tests for evaluating the leakage and pressure resistance of solar collectors are described in test methods 7.11 and 7.12 of NBSIR 78-1305A [4].

Commentary — A hydrostatic test pressure of 1-1/2 times the design pressure is considered a standard test pressure [17]. For most applications, clear water is used. If the water temperature is not approximately that of the ambient atmosphere, sweating will result and proper examination will be difficult. In addition, the use of hot liquids can result in the swelling of packings and joint materials, thus, concealing leaks. Some fluids such as silicones and hydrocarbons have surface tensions less than water and special care must be

given to joints and connections. Some pipe dopes may not be compatible with antifreezes and special thread sealers may be needed. It is advisable to consult the fluid manufacturer for recommendations. Some organic materials used for expansion tank diaphragms, valve seats and sealants may be incompatible with glycols and may lead to leakage. Some leakage in valve and pump stuffing boxes and packing glands may be a normal operating characteristic. Bleeder valves of petcocks should be provided at the highest point or points in the system to permit venting of all air in the piping during the filling operation.

2.2.2 Criterion — Leakage Test: potable water. Those portions of installed H/C/HW systems that are directly connected to the potable water supply system shall not leak when tested in accordance with applicable local and nationally recognized codes and standards.

Evaluation — Review of drawings and specifications.

Commentary — See Commentary for 2.2.1.

2.2.3 Criterion — Leakage and over-pressure testing: air systems. All solar system ducting and thermal storage components that operate at air pressures of 0.10" wg or greater shall be capable of complying with the requirements for leakage and pressure required for air ducts and connectors by UL Standard 181 [18]. The complete air solar system shall be constructed in accordance with SMACNA standards [12] for air leakage and workmanship.

Evaluation — Review of drawings and specifications and testing per UL 181. Provisional tests for evaluating the leakage and pressure resistance of solar collectors are described in test methods 7.11 and 7.12 of NBSIR 78-1305A [4].

Commentary — This criterion is not intended to imply that each component be tested in accordance with UL 181 [18] but only that component construction and field installation provide assemblies that will control air leakage. SMACNA [11] suggests a limit on duct leakage of 5 percent. The criterion is intended to apply to active air solar systems and not to passive systems.

Control of air leakage in active and passive air solar systems both in and out of the system and also within the system at dampers is very important to satisfactory system performance. It is of greater importance in active air solar systems than in conventional forced air heating systems for several reasons: (1) air pressure in the system is usually higher, (2) there usually is more ducting, (3) the system runs more hours, and (4) there may be more ducting through unheated space. Although leakage to heated spaces during the heating season may contribute to satisfaction of the load, this represents a loss of control of the air stream and may compromise total system operation. In particular, severe leakage at the thermal storage unit can result in storage becoming almost ineffective. Furthermore, leakage can result in space overheating.

To prevent excessive leakage, ducts should be sealed in accordance with the SMACNA standard which keys sealing techniques to operating pressure. To reduce internal leakage, low loss dampers will often be necessary.

2.3 Requirement — Collector orientation and location. The collector subsystem shall be located, and oriented, as required by the design to capture sufficient solar energy to meet functional requirement.

2.3.1 Criterion

Tilt and azimuth. The collector shall be installed on a mount capable of maintaining tilt and azimuth to design conditions.

Evaluation

Review of drawings and specifications.

Commentary

Collectors can either be fixed, require seasonal adjustment, or be continuously movable. Detailed information concerning orientation is given by ASHRAE [19]. It is not the intent of this criterion that the collector necessarily be reoriented or tilted after initial installation.

Commonly used values for collector tilt are: latitude plus 10^{o}-15^{o} for space heating systems and tilt equal to latitude for domestic hot water systems. Deviations of $\pm 15^{o}$ from these values when using conventional flat plate collectors will usually have little effect [6]. Conventional flat plate collector orientation should be such that the effective aperture generally faces south. However, deviations to the east or west up to 20^{o} may not result in a significant decrease in incident radiation [6].

Though passive apertures are usually vertical due to structural and architectural considerations, these angles for glazing are still desirable as they minimize reflective losses. Control of overheating is another factor which affects the choice of glazing angle for passive systems.

2.3.2 Criterion

Shading of collector. The location and orientation of the collector shall be such that it is not shaded by external obstructions or mutual shadowing more than the specified period allowed for in the design.

Evaluation

Review of calculations or drawings estimating the area of the collector shaded by objects such as mechanical equipment, chimneys, vents, snow, trees, buildings, and other portions of the collector. Consideration shall be given to the latitude of the site, the height of the object above the collector, the azimuth angle of the object relative to the collector and the cut-off angles at which solar energy can be efficiently collected throughout the year.

Commentary

In locating trees in order to minimize the amount of shade falling on the collector, the designer may not be able to effectively use shade trees to improve the microclimate. Data are available for calculating shading angles as a function of the time of day and year [20,21,22,23]. Consideration should also be given to partial shading of collectors which could cause unusual stress concentrations and resulting glass breakage in an operating collector.

2.4 Requirement

Heat transfer fluid quality. Provision shall be made to maintain the quality of the heat transfer fluid at a level that does not impair its heat transfer function, or create a health hazard.

2.4.1 Criterion

Liquid quality. The systems shall have filters or other means to prevent contamination by foreign substances that could impair the flow and quality of the heat transfer fluid beyond acceptable limits.

When make-up water is of such a quality that excessive corrosion is known to exist, a suitable water treatment system as recommended by the Water Quality Association shall be provided [24].

The chemical composition of the heat transfer liquid shall be maintained at levels adequate to prevent unacceptable deposits on the heat transfer surfaces, corrosion of the surfaces with which the heat transfer liquid comes in contact, or loss of freeze resistance by providing suitable devices or procedures.

Evaluation — Review of piping drawings and specifications.

Commentary — The piping in some solar collectors and heat exchangers may have small cross sections in which blockage by dirt, scale, pieces of gasket material, pieces of packing, or other foreign matter in the heat transfer fluid could occur. The buildup of sludge may be the result of decomposition of the heat transfer liquid, reactions with additives within the liquid itself or reactions of the heat transfer fluid with piping materials or extraneous impurities such as pipe dope, solder flux, cutting oils or general system dirt. To aid in preventing sludge (especially in the heat exchanger and when antifreeze solutions are used), the system piping should be thoroughly cleaned and flushed prior to the introduction of the antifreeze mixture. Problems can develop when liquids such as "hard" water are used. Fluid viscosity at all operating conditions must be properly matched by pump capacity and operating power, see Section 5.2.2. Antifreeze solutions may lose their freeze protection capability over time due to deterioration or the addition of "make-up" water. Provisions for sampling the heat transfer liquid without imparing system operation should be available.

2.4.2 Criterion — Air quality. Adequate means shall be provided to prevent the accumulation of dust, dirt or water that could result either in a reduction of system efficiency or to deterioration of system components.

Evaluation — Review of drawings and specifications.

Commentary — The gravel used for rock bed storage with air systems should be selected for size and freedom from dirt and dust. The use of smooth and washed material and of filtered air is desirable. The possibility of dirt buildup in collectors and/or heat exchangers should also be considered.

To facilitate rock bed washing, remove drain water that may have leaked into the storage container, or to remove condensed moisture, it may be desirable to construct rock storage containers with water resistant interior surfaces and drainage provisions.

2.5 Requirement — Subsystem isolation. Shutdown of the subsystems in one dwelling unit shall not impair the distribution of energy to other dwelling units of the building.

2.5.1 Criterion — Shutdown in multifamily housing. The shutdown of the H/C/HW subsystems in one dwelling unit of a multifamily housing complex shall not interfere with the operation of the subsystems in other dwelling units.

Evaluation — Review of drawings and specifications.

Commentary — This is to permit the shutdown of equipment in an individual dwelling unit for repairs without impairing the operation of the equipment in other dwelling units that are connected to the same central system. Shutdown of the solar system shall not impair the distribution of energy to dwelling unit subsystems, nor safety provisions as provided for in section 4.2.2.

Isolation valves around pumps, heat exchangers and storage tanks (where pressurized) will simplify repairs.

2.6 Requirement — Control subsystem design. The control subsystem shall be designed to operate the H/C/HW system in a safe and effective manner.

2.6.1 Criterion — Temperature sensors. Temperature control sensors shall be protected from detrimental extraneous heat flows.

Evaluation — Review of drawings, specifications and system diagrams.

Commentary — Problems of sensors giving erroneous readings of system operating conditions have been experienced because of heating or cooling in the immediate vicinity of the sensors due to extraneous heat flows. Both degraded performance or system failure by freeze up can result from the occurrence. Extraneous heat flows may result from solar radiation, wind, ambient temperature and thermal gradients including thermosyphoning. They may also be associated with storage tanks, boilers, or hot or cold pipes when sensors are nearby.

Proper insulation of sensors will reduce their susceptibility to the influence of external heat flows. Proper placement of sensors or use of check valves or backdraft dampers will reduce their susceptibility to the influence of internal flows such as thermosyphoning.

Proper installation (attachment, calibration, location) of sensors is also critical in assuring proper performance.

2.6.2 Criterion — Fluid flow control. Controls shall maintain the H/C/HW system within the temperature and pressure operating limits as required by the design.

Evaluation — Review of drawings and specifications.

Commentary — In systems which are not capable of withstanding thermal shock created by filling hot collectors with cool fluids, control subsystems may be required to protect the system from cold filling. Such controls would limit filling to cool periods. Requirements for thermal shock resistance of components and materials are presented in section 5.2.1.

Control provisions may also be required for the dumping of heat when temperatures and pressures approach unacceptable levels. Under such conditions, deterioration of components may occur and/or system function may be imparied due to such factors as boiling, vapor locks, vacuum formation or pressure drops. Safety provisions are presented in section 4.2.

2.6.3 Criterion — Installation and maintenance. The control subsystem shall include such provision for bypass, adjustment, or over-ride of manual or automatic controls as is required to facilitate installation, start-up, operation, shutdown, and maintenance.

Evaluation — Review of drawings, specifications and operating procedures.

Commentary — Controls may be needed during installation, start-up, and operation to balance or adjust the system for proper operation. Controls may be necessary to ensure the safety and durability of the system and the building. Other controls may be required for tests or maintenance after the system has been in operation or for seasonal shutdown.

2.7	Requirement	Operational verification. On completion of installation, the system shall be checked for adequate performance of all components as well as the system as a whole.
2.7.1	Criterion	Checkout. Inspection and testing shall be performed on the installation to verify that the system and components are capable of operating as specified in the design and the manuals defined in section 6.2.
	Evaluation	Visual inspection and testing in accordance with the procedures specified in section 6.2.
	Commentary	Monitoring means may involve sensors and indicators or they may be as simple as inspection.

Controls should be checked in operation to determine that subsystems operate at the proper set points, that pumps and fans start and stop properly and that fail safe devices work. Failure or improper operation of sensors and controls have caused many problems. It is recommended that means be provided during installation to allow temperatures and flow rates to be checked during operation of the system. Experience has shown that poor design and improper installation of components is a major cause of system malfunction and that a large proportion of mechanical failures are apparent within a short period of operation. Incorrectly wired controls, improper control set points, improper component location, reversed components, improper sensor installation, etc., are examples of such misapplications.

It is important to check distribution systems to assure that all areas intended to receive heating and cooling in the design receive it in the actual installation. This is particularly important with passive systems.

References 2

1. National Solar Heating and Cooling Demonstration Program Project Experience Handbook, Preliminary Draft, DOE/CS-0045/D, U.S. Department of Energy, September 1978.

2. National Standard Plumbing Code, as recommended by the National Association of Plumbing-Heating-Cooling Contractors, Appendix B, 1971.

3. ASHRAE Handbook/Systems - 1976.+

4. Provisional Flat Plate Solar Collector Testing Procedures, First Revision, NBSIR 78-1305A, National Bureau of Standards, Washington, D.C., September 1977, PB 272 500.*

5. ASHRAE Handbook/Equipment - 1975.+

6. Duffie, J. A. and Beckman, W. A., Solar Energy Thermal Processes, John Wiley and Sons, New York, N.Y.

7. Testing, Balancing and Adjusting of Environmental Systems, Sheet Metal and Air-Conditioning Contractors National Association (SMACNA), 8224 Old Court House Road, Vienna, Va. 22180, 1974.

8. ASHRAE Handbook of Fundamentals - 1977.+

9. The Standards and Manuals of the National Environmental System Contractors Association (NESCA), 150 Wilson Blvd., Arlington, Va. 22209.

10. Baughn, J. W. and Dougherty, D. A., "Experimental Investigation and Computer Modeling of Solar Natural Circulation System," Proceedings of the 1977 American Section of ISES Annual Meeting, Orlando, Fla.

11. ASHRAE, Applications of Solar Energy for Heating and Cooling of Buildings, 1977, GRP 170.+

12. Heating and Air-Conditioning Systems Installation Standards for One and Two Family Dwellings and Multifamily Housing Including Solar, SMACNA, 1977.

13. Standard for Sound Rating of Room Fan-Coil Air-Conditioning (ARI 443-71) and Air Induction Units (ARI 446-68), Air Conditioning and Refrigeration Institute, 1915 North Fort Myer Drive, Arlington, Va. 22209.

14. National Fire Codes, National Fire Protection Association, 470 Atlantic Avenue, Boston, MA. 02210

15. American National Standard, Water Hammer Arresters, ANSI A112.26.1, American National Standards Institute, 1430 Broadway, New York, N.Y. 10018, 1969.

16. Windenburg, D. F., "Vessels Under External Pressure," Mechanical Engineering, pp. 601-607, January 1937.

17. ASME Boiler and Pressure Vessel Code, Section VIII, Subsection U99, Standard Hydrostatic Test, American Society of Mechanical Engineers.

18. Factory Made Air Duct Materials and Air Duct Connectors, UL Standard No. 181, 1974.**

19. ASHRAE Handbook/Applications - 1974.+

+ American Society of Heating, Refrigerating and Air-Conditioning Engineer, 345 East 47th Street, New York, N.Y. 10017.
* National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161.
**Underwriters Laboratories, Inc., 333 Pfingsten Road, Northbrook, Ill. 60062.

20. Tabor, H., "Stationary Mirror System for Solar Collectors," Solar Energy, Vol. II, pp. 3-4, July-October 1958.

21. Aronin, Jeffrey E., Climate and Architecture, Reinhold, New York, N.Y., 1953.

22. Libbey-Owens-Ford Co., Sun Angle Calculator, Libbey-Owens-Ford Co., Toledo, Ohio, 1975.

23. United Nations, Climate and House Design, United Nations Publication, New York, N.Y., 1971.

24. Water Quality Association, 447 East Butterfield Road, Lombard, Ill. 60148, 1974.

(Note: This chapter has been significantly reorganized from "Interim Performance Criteria for Solar Heating and Combined Heating/Cooling Systems and Dwellings," Jan 1975)

The performance requirements and criteria in this chapter deal with the ability of systems and elements to maintain their structural integrity under in-service and extreme conditions. Factors such as wind, snow, operating, seismic, and thermal restraint loads are considered. Typical failures that are to be avoided might include: the collapse of a frame supporting solar collectors due to wind, snow, or earthquake; the leaking or collapse of an underground thermal storage tank; the blowing off or fracture of a glass cover plate due to wind, the impact of hail, or thermal stresses.

Note that these requirements apply to all elements of a solar system, not just those with a function of providing support for some other element. In this regard, there is an important distinction made between conventional elements, those elements for which design and construction procedures are contained in existing building regulatory documents, and non-conventional elements, those elements for which such procedures are not available. Elements made of materials documented in existing building regulatory documents, such as structural steel, aluminum, timber, glass, masonry, concrete, etc., that will be exposed to service conditions that are normally considered in such documents are examples of conventional elements. New materials such as a new alloy of aluminum, or conventional materials exposed to an unusual environment such as welded steel subjected to unusually high or low temperatures, or plastics subject to high and low temperatures are examples of non-conventional elements. Elements with a structural support function will generally be conventional, and the structural requirements for these elements will usually be satisfied by the designer for the particular installation. Elements with primary functions other than structural support may frequently be non-conventional, and the structural requirements for these elements will typically be satisfied by the manufacturer of the element.

3.1 Requirement — Structural safety of H/C/HW system. The elements and connections of the H/C/HW systems shall safely support all loads expected during the design life of the systems without failure.

3.1.1 Criterion — Conventional elements, load and resistance. The resistance, R, of the conventional elements and connections of the system shall exceed the required design load U.

The resistance, R, of conventional elements shall be determined by reference to Section 601 of the MPS [1, 2, 3].

The design load, U, shall be combined from the following loads in accordance with Section 601-10 of the MPS:

1. Dead loads (D) shall be the "Dead Loads" stipulated in Section 601-3 of the MPS.

2. Live loads (L) shall include all static and dynamic loads exerted by the operation of the solar energy system and all applicable live loads from Section 601-4 of the MPS and all appropriate maintenance loads. Surfaces that must support maintenance personnel shall resist a single concentrated load of 250 lbs. distributed over 4 square inch area at the most critical locations. This shall also include vehicular loads as stipulated by AASHTO [4] on elements at or below grade subjected to traffic.

3. Snow and ice loads (S) shall include the snow loads stipulated in Section 601-5 of the MPS and, for slender elements such as wires and slender pipes, the ice loads stipulated in Section 1 of Appendix 3.

4. Soil and water pressures (H) on buried elements shall be in accordance with accepted principles of soil mechanics and Section 601-8 of the MPS.

5. Wind loads (W) shall be "Wind Loads" stipulated in Section 601-6 of the MPS.

6 Earthquake loads (E) shall be those stipulated in Section 601-2.2 and 601-9 of the MPS. For components and connections which cannot be evaluated within the scope of the referenced provisions, the value of "C_p" (horizontal force factor) shall be taken as 1.0.

7. Constraint loads (T) caused by temperature changes, shrinkage, moisture changes, normal functioning of the system, time-dependent changes within the materials of the system, and by differential movement of the supporting structure and foundation settlement shall be taken as the most severe likely to be encountered during the service life.

8. The load from ponding of water on large horizontal surfaces.

Evaluation

Review of design drawings, specifications, and calculations.

Commentary

The intent of this criterion is that conventional elements and systems continue to be designed in accordance with applicable building code documents. Note that most of the loads in the MPS are referenced from ANSI A58.1-1972 [6].

There are circumstances in which common building materials cannot be considered conventional because they are exposed to unusual service conditions. See, for example, the discussion of structural work in the commentary of section 3.1.2.

It is recognized that some elements will be designed using the ultimate resistance and factored loads while others will be designed using an allowable resistance and unfactored loads. The loads presented are those expected to occur in the projected lifetime of the installation. Particular attention should be given to the load caused by the thermal cycling of the system, both under normal conditions and "no-flow" conditions.

The following paragraphs of commentary are numbered corresponding to the loads listed under the criterion:

(2) The design live loads contained in the MPS for roofs constitute minimum loading requirements needed primarily for human safety while the building is undergoing maintenance. Resistance to these loads need not be required for collector panels that are mounted on roofs without forming an integral part of the roof if adequate access is provided for service and maintenance personnel. For collectors which form an integral part of the roof, resistance to the design live roof loads listed in the MPS should be required, because the roof will need to be repaired from time to time and must support the workman making the repairs.

(6) The value of "C_p" supplied for elements that are not specified by the referenced provisions is consistent with conservative values for elements appended to structures.

(7) The possibility of stresses being imposed by thermal expansion or contraction, wind movement, seismic loads, vibratory loads, or foundation settlement need to be considered. Solar components vary in their ability to withstand the effect on their performance of differential settlement. For example, a rock storage bin can probably settle a great deal without affecting its performance; however, a plumbing connection may be able to withstand very little differential settlement.

Time dependent changes within materials of the system should include consideration of materials degradation. Of particular concern may be deterioration of plastics and organic materials, corrosion and eletrolytic action between dissimilar metals such as between a collector and its support. Materials degradation is further discussed in Chapter 5.

(8) Ponding is defined as the retention of water due to the deflection of horizontal surfaces. Measures to resist ponding include providing sufficient stiffness to prevent excessive deflections, providing slope to carry excess water away, providing drains to remove water, or providing overflow locations to limit the depth of water.

3.1.2 Criterion

Nonconventional elements, resistance to maximum load. The factored resistance, R*, of the nonconventional elements of the system or a portion thereof shall exceed the factored load, U*.

R* shall be determined from Section 2 of Appendix 2 (reference [7] presents detailed procedures for determining the resistance, R*, of flat plate solar collectors) and U* shall be determined as follows:

for additive loads, $U^* = 1.1\,\overline{D} + 1.5\,(\overline{Q} + \Sigma\Psi_i\overline{F}_i)$

for counteracting loads, $U^* = 1.6\,\overline{Q} - 0.8\,\overline{D}$

WHERE:

$\overline{D}$ = mean dead load, D, as stipulated in 3.1.1
$\overline{Q}$ = mean maximum variable load, see below
$\Psi_i\overline{F}_i$ = mean transient load(s) acting simultaneously with $\overline{Q}$

$\overline{Q}$ shall be any one of the following loads and $\overline{F}_i$ shall include all of the remaining loads:

1.25 L)
1.2 S)
1.0 H)
0.85 W) where L, S, H, W, E, and T are as stipulated in 3.1.1
1.4 E)
1.0 T)

Ψ_i shall be determined from the following table, or from a rational analysis of the expected load combinations:

F_i	L	S	H	W	E	T
Ψ_i	0.65	0.25	1.0	0	0	1.0

Constraint loads (T) shall be explicitly allowed for by considering the extreme operating temperature range and by considering a differential foundation settlement of 2 inches in any horizontal distance of 50 feet in addition to those conditions specified in 3.1.1, except that in cases where a particular foundation is specifically designed to control differential settlements, the differential settlements used for T should be those consistent with the specified design. Uplift forces caused by a swelling of expansion soils shall be calculated assuming a level of 0.9D for gravity loads.

Evaluation

Review of design drawings, specifications, calculations, and documentation of this resistance as described in section 2 of Appendix 2. The provisional tests described in sections 7.7, 7.8, and 7.9 of NBSIR 78-1305A [7] provide one means of determining the effects of positive and negative live loads and longitudinal loads on flat plate solar collectors and their mounting hardware.

Commentary

Considerable care is required to determine the resistance of non-conventional elements. Section 2 of Appendix 2 gives procedures for determining the nominal resistance from the statistics of the random variables involved.

For experimental or analytical evaluation of structural response, the selection of the system components shall be done in a manner representing the least margin of safety to the system but consistent with its interaction with structural systems to which they are attached. Test loads applied to the system components shall result in the most critical conditions encountered in service. Additional eccentricities of loading caused by drift due to lateral loads and anticipated differential foundation settlements shall be provided for in tests of supporting structural elements of the system. The effects of service history caused by fatigue, sustained load, temperature, moisture, ultraviolet light or other environmental factors shall be provided for in tests. Reference [7] gives detailed procedures for testing and rating flat plate solar collectors.

In some circumstances, such as collectors framed in wood or attic collectors, wood and cellulosic materials may be subject to sustained or cyclic elevated temperatures for extended periods of time (years). Under such conditions, strength reduction of structural members may be very significant and should be considered [8, 9]. Uneven heating of such structural members may cause racking or twisting during the normal course of the day. This should be accounted for in the design of the structure.

When physical testing is done to establish values for the resistance, care should be taken to assure that all significant interactions with other positions of buildings and environmental effects are properly accounted for. For example, when testing single stories of high rise buildings, the effect of lateral drift above the story in question should be added to the loads. Possible environmental factors that may be important include temperature, moisture, ultraviolet light and atmospheric pollution. The resistance to long term sustained loads and to repeated loads are frequently important, and fatigue is covered in section 5.4.

The intent of the criterion is to provide a minimum level of safety against loading situations which have a suitably high probability of not being exceeded during the service life. Decisions regarding structural safety are invariably made in the presence of uncertainties which arise from basic randomness in many of the resistance and load parameters as well as imperfect modeling and information. Indeed, it is these uncertainties which motivate and necessitate the use of safety factors in design. The recent trend to use probabilistically derived resistance and load factors in structural design represents an attempt to proportion members and connections so that the probability of attaining any limit state is acceptably small. The load factors represent present day design practice of building structures and are similar to the load factors proposed for use in an innovative construction [10]. These factors will also produce ultimate loads comparable to those presently used in the design of steel and concrete structures. Adoption of a similar level of performance requirements for the H/C/HW systems will permit the designer to explore the potential use of system components as structural elements in addition to their primary heating and/or cooling function.

It should be noted that combining effects from several loads is not always a simple task, and the formula given for combinations in this document must be used with some judgment. For example, it may be possible for some materials to relieve the effect of constraint loads through creep or by yielding. Thus for some ductile materials, it would not be necessary to consider constraint loads acting simultaneously with earthquake loads because the structure would be expected to yield during the earthquake.

Due to economic considerations in foundation design, the assumption is usually made that the conventional structures are capable of accommodating a reasonable amount of differential settlement. The prescribed foundation settlement is consistent with observed performance of conventionally designed foundations and represents the threshold at which structural damage occurs. This criterion is relaxed when special precautions are used in foundation design to control differential settlements.

3.1.3 Criterion

Nonconventional elements, resistance to cyclic loads. Nonconventional elements shall be capable of resisting the expected repeated loads without failure or visible cracking but in no case shall these repeated loads be taken as less than 500 cycles from $\bar{D}$ to $\bar{D} + 1/2\ \bar{Q}$ where $\bar{D}$ and $\bar{Q}$ are defined in Criterion 3.1.2.

Evaluation

Physical simulation and testing or analysis based on available test data.

Where physical simulation is used, the cyclic loading shall be applied after reducing system slack by the prior application of one preloading cycle of $\bar{D} + \bar{Q}$.

Cyclic loading shall commence only after deflection recovery from the preloading cycle is substantially complete. The residual deflection shall be taken as the difference between the deflection measured 24 hours after removal of the superimposed cyclic load and the residual deflection, if any, not recovered from the preloading cycle, and it shall be less than 25 percent of the maximum deflection in the first cycle.

Commentary — Even though the service load history cannot be simulated, the imposition of the stipulated cyclic load is intended as a conservative representation of service conditions. The residual deflection limitation assures preservation of structural integrity under cyclic loading.

3.2 Requirement — Function and operation. The elements of the solar energy system shall not impair the function or operation of the solar energy system when exposed to structural loads.

3.2.1 Criterion — Conventional elements, deflection limitations. The deflection of conventional elements supporting the system elements shall not exceed the limits of Section 601-11 of the MPS.

Evaluation — Review of design drawings, specifications, and calculations.

Commentary — Conventional deflection limitations are formulated to fulfill many requirements. Where it can be demonstrated that Requirement 3.2 is satisfied, the empirical limit may be justifiably modified.

3.2.2 Criterion — Nonconventional elements, deflection limitations. The deflection of nonconventional elements supporting the system components shall not exceed the following limitations:

(a) With the full dead load (1.0D) in place, the net deflection measured after the element has sustained a superimposed load of 0.2D + 1.5L for 24 hours shall not exceed the following two limits:

$$d_2 \leq \frac{1.25s}{180} \times \frac{0.2D + 1.5L}{L}$$

$$d_2 \leq 1.25\, d_1$$

where: s = span length
d_1 = net deflection measured immediately after application of the superimposed load

(b) The maximum residual deflection (d_3) measured not more than 24 hours after removal of the superimposed load specified in (a) shall meet the following conditions:

$$d_3 \leq .25d_2 \text{ or } s/4000, \text{ whichever is greater}$$

Evaluation — Analysis and/or physical simulation, including tests on prototype support structure. Deflections shall be measured in a direction normal to the span and shall include the deflection of the supporting members.

One preloading cycle is permitted, provided that loading in the actual test does not commence before deflection recovery from the preloading cycle is substantially complete.

Commentary — Loads lower than required ultimate loads should not cause large, irrecoverable deformations. It is not unreasonable to require non-conventional structures to resist the stipulated superimposed loads without resulting in significant residual deformations. The limitations in part (a) implies deflection limitation of s/180 under service live load (1.0 L) with an additional 25 percent allowance for creep.

Part (b) requires 75 percent elastic recovery of deflection except for very stiff systems. This guards against significant residual deflection increases in each cycle of loading that may lead to incremental collapse.

Where brittle components are attached to supporting elements, particular attention shall be paid to Criterion 3.2.3, as it may require more stringent limits on deflection.

3.2.3 Criterion

Deflection compatibility. Under the effect of deflections caused by the loads defined in Criterion 3.1.1, in addition to the anticipated creep deflections, the system as a whole or any component, connection or support thereof, shall not suffer permanent damage which would require replacement or repair, or which would impair its intended function during its service life.

Evaluation

Evaluation of documentation of data for design, tests, installations. Evaluation and/or testing of components and elements where deemed essential. Determination of compliance with generally accepted standards and engineering and trade practices, where applicable.

The criterion is deemed satisfied if it can be demonstrated that deflections caused by the specified loads can be accommodated by suitable details or adequate flexibility.

Commentary

The intent of this criterion is to provide for the proper functioning of the system under service loading conditions without breakdown or permanent impairment beyond levels comparable to conventional heating and cooling systems.

Reference [11] gives a range of limits on deflection depending on circumstances that may be used for guidance in assessing compatibility.

3.2.4 Criterion

Hail damage. All system components and supporting structural elements that will be exposed to the natural environment in service shall resist, without excessive damage or major impairment of the functioning of the system, the impact of falling hail as stipulated in Section 3 of Appendix 2.

Evaluation

Evaluation will be based on analysis using known structural information on the physical characteristics of the system components or on physical simulation and testing using the hail resistance test described in Section 3 of Appendix 2.

In cases where protective measures are provided to prevent impact of hail on system components, such as the use of screens or deflectors, these protective measures shall be included in the test specimen.

Commentary

It is not the intent of this criterion to completely prevent punching or local cracking of nonstructural elements such as cover plates of collector panels under hail impact, but rather to control damage by keeping it at a level which would not create a major curtailment in the functioning of the system, premature failure or hazards created by excessive shattering of glazed elements.

References 3

1. HUD Minimum Property Standards, One and Two Family Dwellings, (No. 4900.1), U.S. Department of Housing and Urban Development, Washington, D.C. (1973, revised 1976)+

2. HUD Minimum Property Standards, Multifamily Housing, (No. 4910.1), U.S. Department of Housing and Urban Development, Washington, D.C. (1973, revised 1976)+

3. HUD Minimum Property Standards, Care-Type Housing, (No. 4920.1) U. S. Department of Housing and Urban Development, Washington, D.C. (1973 revised 1976)+

4. Standard Specification for Highway Bridges, AASHTO, Washington, D.C. 1973.

5. Uniform Building Code, 1976 Edition, International Conference in Building Officials, Whittier, California 90601, 1976.

6. Building Code Requirements for Minimum Design Loads in Buildings and Other Structures, American National Standards Institute, ANSI A58.1 - 1972.

7. Provisional Flat Plate Solar Collector Testing Procedures, First Revision, NBSIR 78-1305A, National Bureau of Standards, Washington, D.C. June, 1978.

8. Wood Handbook, 1974 p. 4-32-4-40, Forest Products Laboratory, Madison, Wisconsin.

9. MacLean, J.D., "Rate of Disintegration of Wood Under Different Heating Conditions," American Wood Preservers Association, 1951.

10. Performance Criteria Resource Document for Innovative Construction, NBSIR 77-1316, National Bureau of Standards, Washington, D.C., November 1977.*

11. Building Code Requirements for Reinforced Concrete, ACI 318-71, American Concrete Institute, Detroit, Michigan, 1971.

+Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

*National Technical Information Service, 5285 Port Royal Road., Springfield, VA 22161

4.1 Requirement

Health and safety. The design and installation of the H/C/HW systems/subsystems and their components shall be in accordance with nationally recognized standards for health and safety including the HUD MPS 4900.1, 4910.1, 4920.1, and 4930.2 for residential and care type housing [1, 2, 3, 4,].

4.1.1 Criterion

Plumbing codes and standards. Plumbing materials and equipment and their installation shall be in accordance with applicable local and nationally recognized plumbing codes and standards.

Evaluation

Review of drawings and specifications. Testing to show compliance where necessary.

Commentary

Suitable standards are available for conventional equipment. Unique, innovative installations may require special consideration.

4.1.2 Criterion

Electrical codes and standards. Electrical materials and equipment and their installation shall be in accordance with applicable local and nationally recognized electric codes [5] and with applicable standards of American National Standards Institute (ANSI), National Electrical Manufacturer's Association (NEMA), Underwriter's Laboratories (UL) and HUD. Electrical components, wiring, switching, and protective devices shall be approved or listed by a nationally recognized testing laboratory.

Evaluation

Review of drawings and specifications. Testing to show compliance where necessary.

Commentary

Suitable standards are available for conventional equipment. Unique installations may require special consideration.

4.2 Requirement

Fail-safe controls. The H/C/HW systems shall be fail-safe for operation under all anticipated conditions (normal and "no-flow") and in the event of damage to system components or a power failure.

4.2.1 Criterion

System failure prevention. The control subsystem shall be designed so that, in the event of a power failure, or a failure of any of the components in the system, the temperatures and/or pressures developed in the H/C/HW systems will not present a danger to the occupants or damage any of the components of the system or the building. Safety devices when used shall meet the requirements of Section 515 and 615 of the MPS [1, 2, 3].

Evaluation

Review of drawings, specifications, and design calculations.

Commentary

The excessive pressure and temperatures that can build up on collectors under "no-flow" conditions are an important consideration. Consideration should be given to the thermal shock which could occur when cool heat transfer fluids are introduced into collectors which have been exposed to solar radiation under "no-flow" conditions. Due to the possibility of large hydrostatic head pressures on tanks that may be greatly in excess of pressures elsewhere in the system, care should be taken in the selection of the location of safety devices. In systems which are not capable of withstanding the maximum temperatures to which they will be exposed (i.e., under "no-flow" conditions) it is essential that some means of protection such as energy dumping be provided.

4.2.2 Criterion

Automatic pressure relief devices. Adequately sized and responsive automatic pressure relief devices shall be provided in those parts of the energy transport subsystem containing pressurized fluids. A pressure relief device shall be provided in each portion of the subsystem where excessive pressures can develop. Each such section of the system shall have a pressure relief device so that no section can be valved off or otherwise isolated from a relief device. Automatic pressure relief devices shall be set to open at not more than the maximum pressure for which the subsystem is designed. Vented potable liquids shall be piped to suitable drains. Non-potable or combustible liquids shall be handled in accordance with Criterion 4.4.5.

Relief valves shall drain to locations acceptable to the local administrative code authority. It is desirable to provide a means of detecting when pressure relief has occured (i.e., when recharging is necessary).

Evaluation

Review of drawings and specifications and/or determination that methods, devices, and materials to be used are approved by a recognized testing and evaluation agency as being suitable for the proposed use.

Commentary

Care should be taken in the design and layout of the fluid transport system to prevent conditions in which locally excessive pressures are developed as a result of flow restrictions or air locks. Large pressure drops due to flow of vapors or boiling fluids should be considered in the selection and location of pressure relief devices. Relief devices must be protected from freezing as conditions can occur when pressure relief is needed and exposed or otherwise chilled relief valves could be frozen. Precautions must be taken to assure that heat transfer liquids do not discharge on asphalt base roofing materials or other types of roofing or locations which may be hazardous, cause structural damage, building finish discoloration, or damage to plant materials.

4.2.3 Criterion

Protection from scalding. Domestic hot water systems shall be equipped with means for limiting temperature of the hot water for personal use at fixtures to 140°F.

Evaluation

Review of drawings and specifications.

Commentary

This may be accomplished, for example, by the use of mixing valves or by limiting solar energy input (heat dumping).

4.3 Requirement

Fire safety. The design and installations of the H/C/HW systems and their components shall provide a level of fire safety consistent with applicable codes and standards including those of HUD [1, 2, 3, 4] for the type of housing to which it is applied.

Commentary

It is the intent of the requirement to (1) prevent the use of materials, equipment and fluids which present a fire hazard greater than that allowed for conventional systems; (2) provide proper clearance and venting of heat build-up for those system components that operate at elevated temperatures; and (3) give consideration to the combustibility of materials adjacent to high temperature components in determining the clearance and/or insulation required. Special consideration should be given to the fire safety features of innovative system designs particularly those utilizing insulation in a way which may present a greater hazard than with conventional designs such as passive system thermal control elements.

4.3.1 Criterion — Fire codes and standards. Assemblies and materials and their installations shall be in accordance with local and nationally recognized codes and standards for fire safety.

Evaluation — Review of drawings and specifications for conformance with the local and nationally recognized codes and standards for fire safety including but not limited to applicable sections of NFPA 89M [7], NFPA 90A [8] and 90B [9], NFPA 211 [10], NFPA 54 [11], NFPA 30 [6], NFPA 31 [12], NFPA 256 [13] and the National Electrical Code [5], and the HUD standards [1, 2, 3, 4]. In cases where sufficient engineering information is not available, testing to show compliance may be required. Potential heat, rate of heat release, ease of ignition, and smoke generation will be considered in assessing the potential fire hazards.

Commentary — The type of testing that should be performed to evalute the influence of solar collectors on the fire resistance of roof assemblies is described in test method 7.13 of NBSIR 78-1305A [14].

Currently, there are no standards that specifically address the fire hazard of combustible materials used in the collector, thermal storage or heat exchange portions of a solar air distribution system.

4.3.2 Criterion — Flame spread classification of insulation. The flame spread classification index for all insulation materials except those installed underground and outside the structure shall not exceed the following values:

Plastic Foam	75
Other Insulation Materials	150*

Insulation materials used for duct liners shall meet the requirements of either NFPA 90A [8] or 90B [9], whichever is applicable.

Evaluation — The ASTM E84 [15] flame spread test method shall be the basis for evaluating the surface burning characteristics of the insulation materials. Where materials with facings are to be used, the surface burning characteristics of the faced material shall be measured.

Commentary — No single test is sufficient to provide a full estimate of performance of a product in a fire. Plastic foams and loose fill insulation are difficult to evaluate in ASTM E84. The requirement of flame spread classification of 75 maximum for plastic foams will provide as much safety assurance as is possible with current test methods. Such a classification shall not be construed as the equivalent of "noncombustible." Many insulation materials, including those consisting of cellulose, plastic foam and fibrous glass (containing organic binder) are combustible materials which will burn and release heat, especially when exposed to continuous large fire sources.

4.3.3 Criterion — Areas of application. Materials used for thermal insulation shall be in accordance with Criterion 4.3.2 and may be applied to the following areas: walls, roofs, ceilings, floors, pipes, ducts, vessels and equipment exposed to the external environment.

*The Consumer Product Safety Commission "Interim Safety Standard for Cellulose Insulation," Federal Register, Volume 43, No. 153, p. 35240, became effective on September 8, 1978 and supersedes these requirements for cellulose insulation. Modifications to this standard are under consideration by CPSC.

Exposed plastic foam (untreated or fire-retardant treated), Kraft-asphaltic vapor barrier on mineral and organic fiber insulations, and non-fire-retardant treated loose fill insulation shall not be permitted in habitable areas unless fully protected from the interior of the building by a thermal barrier having a finish rating of not less than 15 minutes as determined by NFPA 251 [16]. Thermal barriers shall be installed in a manner such that they will remain in place for a minimum of 15 minutes under the same test conditions.

Installed insulation and vapor barriers shall not make contact with pipes or pumps containing hot fluids, motors, fans, blowers, and heaters, unless the insulation and/or the heat producing appliances are specifically designed and rated for that purpose.

Evaluation — Review of drawings and specifications.

Commentary — Although a degree of material combustibility is allowed, the intent is to allow insulating materials which are not more combustible (or flammable) than existing construction and insulation materials, and to preclude any increased fire hazard due to the retention of heat from energy dissipating objects. Electric circuit wires which are surrounded by substantial thermal insulation may be subject to overheating. In areas where occupants are likely to be engaged in normal activities, the insulation should perform its intended function without the increased risk of ignition, rapid flame spread and heat and smoke generation. Attention should be given to the requirements as they pertain to innovative insulation systems such as movable and fixed insulation installed as part of passive systems. Insulation in concealed spaces may be a particular fire problem due to its susceptibility to smoldering and its unaccessibility for fire fighting.

4.3.4 Criterion — Flame resistance permanency of insulation. Chemical retardant insulations shall retain their flame resistance throughout their service lifetime.

Evaluation — The procedures and equipment specified in ASTM C739-73, Section 10.4, "Flame Resistance Permanency" [17] shall be used in judging the effect of aging on the permanence of any flame retardants used during manufacture.

4.3.5 Criterion — Penetrations through fire-rated assemblies. Penetrations through fire-rated walls, partitions, floors, roofs, etc. shall not reduce the fire resistance required by local codes and ordinances and applicable HUD standards [1, 2, 3, 4].

Evaluation — Review of drawings and specifications. Testing to show compliance in accordance with NFPA 251 [16] and applicable HUD standards [1, 2, 3, 4].

Commentary — It is the intent of this criterion to (1) prevent the passage of system components through fire-rated assemblies from adversely affecting the fire endurance rating of the assembly in terms of premature collapse of structural elements and (2) ensure that proper techniques are employed in constructing these components so that adequate protection can be provided. Because of the potential fire hazard, use of building elements and areas such as walls, attics, crawl spaces, and as plenums may be subject to restrictions in NFPA 90A [8], 90B [9], and local building codes.

4.3.6 Criterion

Firestopping. H/C/HW system components that are integral parts of assemblies which normally require firestopping shall be firestopped on all sides. Firestopping shall be wood blocking of minimum 2 inch nominal thickness or of non-combustible materials providing equivalent protection. Firestopping may be included as an integral part of the component where the component as installed provides equivalent protection. Firestopping shall comply with local codes and ordinances and applicable HUD standards [1, 2, 3,4].

Evaluation

Review of drawings and specifications

Commentary

It is the intent of this criterion to prevent H/C/HW system components from reducing the effectiveness of firestopping. For example, in the case where a solar collector is an integral part of a wood framed wall which would normally be firestopped between studs, firestopping shall be required in the wall above and below the solar collector.

4.3.7 Criterion

Protection against auto-ignition of combustibles. Combustible solids used in solar equipment and adjacent combustible solids shall not be exposed to elevated temperatures which may cause ignition.

Evaluation

Review of calculations, drawings, and specifications. Testing to show compliance where necessary.

Commentary

Exposure of cellulosic materials as well as other combustible materials over an extended period of time may result in the material reaching and surpassing its auto-ignition temperature. Such conditions may exist, for example, within active collectors framed in wood or inside attic collectors. The most commonly accepted ignition temperature of wood is 392°F. However, studies have indicated that wood may ignite when exposed to a temperature of 212°F for prolonged periods of time. The ignition temperatures of plastics may be above or below those of cellulosic materials. Clearances for HVAC equipment, ducting, and piping are discussed in NFPA No. 89M [7] and 90B [9]. Where applicable, clearances specified by a nationally recognized testing laboratory may be used.

4.4 Requirement

Toxic and combustible fluids. Heat transfer fluids or thermal storage fluids which require special handling (e.g. toxic, combustible, corrosive, explosive, etc.) shall not be used unless the systems in which they are used are designed to avoid unreasonable hazards.

4.4.1 Criterion

Toxic fluids. The use of toxic fluids shall comply with the Federal Hazardous Substances Act [18] and the requirements of the health authority having jurisdiction.

Evaluation

When evaluating the toxicological properties of fluids, special consideration should be given to the effect of a system failure on the occupants. The evaluation should include the effects from contacting both the liquid directly and the vapor given off by the liquid. The toxicological effects of the fluid should be evaluated at the elevated temperatures expected during system operation as well as at ambient temperatures.

Commentary

Toxic fluids are those having the capacity to produce personal injury or illness to man through ingestion, inhalation, or absorption through any body surface [18]. A compilation of the toxicity characteristics of materials used in solar systems has been prepared [19].

Characteristics of the complete fluid mixture must be considered in determining toxicity. For example, the addition of inhibitors and/or buffers to anti-freeze/water mixtures or to water may affect toxicity characteristics.

4.4.2 Criterion

Combustible liquids. The storage, piping and handling of combustible liquids shall be in accordance with the Flammable and Combustible Liquids Code NFPA No. 30 [6].

Evaluation

Review of drawings and specifications.

Commentary

This section applies to those liquids which have met Criterion 4.4.3 for flash point.

4.4.3 Criterion

Liquid flash point. The flash point of a liquid heat transfer fluid shall equal or exceed each of the following temperatures:

A. 100°F;

B. 50°F above the design maximum flow temperature of the fluid in the solar system;

C. (1) 200°F below the design maximum no-flow temperature of the fluid attained in the collector provided the collector manifold assembly is located outside of the building and exposed to the weather and provided that relief valves located adjacent to the collector or collector manifold do not discharge directly into the building, or

(2) the design maximum no-flow temperature of the fluid in all other manifold and relief valve configurations.

A "liquid heat transfer fluid" is defined as the operating or thermal storage liquid including water or other liquid base and all additives at the concentration used under operating conditions. The flash point shall be determined by the methods described in NFPA No. 321 [20], "Basic Classification of Flammable and Combustible Liquids." In systems using a gaseous heat transfer fluid, a flammable gas shall not be used.

The design maximum flow temperature of the fluid is defined as the maximum fluid temperature that will be obtained when the heat transfer fluid is flowing through the system. The design maximum no-flow temperature of the fluid is defined as the maximum fluid temperature that will be obtained when the heat transfer fluid is not flowing through the system. Generally, this temperature will occur in the collector when it is receiving its maximum level of solar radiation at maximum ambient temperature.

Evaluation

Review of drawings, specifications, design calculations and test data for flash point and collector stagnation and operating temperatures. An acceptable way of determining the design maximum flow temperature is by the limiting temperatures of control devices or relief valves, or through theoretical or test analysis of the system. A method of determining the maximum no-flow temperature is presented in test method 7.2 (section 7.2.5.2) of NBSIR 78-1305A [14] where the design maximum no-flow temperature of the fluid is equal to the plate temperature at stagnation. It should be noted that this method is not valid for collectors with very low loss coefficients.

Commentary — Flash point values listed in manufacturer's literature are frequently typical values and may be determined by an open cup flash point test. Flash point values used should be based on actual measurement or certified minimum values determined by the required closed cup flash point test method.

The flash point of aqueous solutions of organic materials depends on the percentage of water in the mixture. In the case of ethylene glycol, a flash point does not exist for certain percentages of ethylene glycol with water. When these mixtures are boiled and the vapors allowed to escape, the flash point of the mixture usually will be reduced, ultimately approaching that of the pure substance. Care should be taken that the flash point of the solution is based on the anticipated percentage of water during actual use of the liquid in the system and not necessarily on the percentage as installed.

A further discussion of temperatures is presented in Appendix 3, Section 1.

4.4.4 Criterion — Detection of toxic and combustible fluids. If heat transfer fluids or thermal storage fluids that require special handling are used, means shall be provided to indicate a failure of the fluid transfer system (e.g. leakage, pump failure, or activation of relief valves) and the provision of warning when leaks occur. The extent of warning (i.e. whether solely maintenance personnel, or all of the occupants of a building) shall be determined on the basis of the degree of hazard presented by the fluid used and the type of occupancy.

Evaluation — Review of drawings and specifications. Testing of detection and warning system(s).

Commentary — It is common practice to relate toxicity and flammability ratings to the level of hazard created at ambient temperatures. Heat transfer fluids which do not present a hazard at ambient temperatures may be hazardous at the temperatures developed in the system. These substances may be treated in a manner similar to antifreeze and gases when providing for tell-tale indicators. For instance, antifreeze agents, such as ethylene glycol; may be treated with non-toxic dyes which distinguish them clearly.

4.4.5 Criterion — Waste disposal. Systems utilizing other than air or potable water as a heat transfer fluid or thermal storage fluid shall provide for the catchment and/or harmless removal of these fluids from vents, drains, re-charge points, or points of potable leakage (i.e. leakage from components that would not normally be expected to last the life of the system) as approved by local administrative code authority. Potable water shall be discharged to suitable drainage systems connected to the building or site drains.

Evaluation — Review of drawings and specifications.

Commentary — The discharge of toxic, corrosive, combustible, or explosive fluids into sewers can create serious health and safety hazards both within the community and at a considerable distance along watercourses into which the sewers discharge. Safe disposal of these fluids requires, among other things, the consideration of the fluid composition, its concentration and frequency of discharge and the nature of the sewage treatment and disposal system available to the site. In some instances catchment of this discharge and removal to specialized treatment facilities may be the only acceptable disposal method. Under such conditions adequately sized and protected catch basins must be provided.

The leakage of toxic fluids into the ground could contaminate ground water. In addition, leakage of some heat transfer fluids can damage roofing, sealants, and other building materials. The leakage of combustible fluids may pose a fire hazard when exposed to external ignition or heat loss.

Some components (for example, connector hoses) which have a shorter life than the system, but which are replaced on a scheduled replacement program which is more frequent than their design life may be considered in aggregate, to last the life of the system.

4.4.6 Criterion

Identification. Drains and other designated fluid discharge or fill points in solar systems at which fluids requiring special handling or high temperature or high pressure fluids may be discharged shall be labeled with a warning summarizing the identification and hazardous properties of the fluid, instructions concerning the safe handling of the fluid, and emergency first aid procedures.

Evaluation

Review of specifications.

Commentary

The original fluid containers will frequently be discarded after the system is charged which could result in no record of the fluid's properties being retained. The system drain is the point at which the owner or service personnel are most likely to contact the heat transfer fluid and permanent labeling should be retained at that point. Identification may be provided by attaching a tag containing the required information such as may be supplied by the heat transfer fluid manufacturer.

4.5 Requirement

Safety under emergency conditions. In the event of emergencies, the H/C/HW systems shall not unduly hinder the movement of occupants of the building or emergency personnel. Life safety hazards which could occur as a result of failures of the above systems shall not be greater than those imposed by conventional systems.

4.5.1 Criterion

Emergency egress and access. The design and installation of the H/C/HW systems shall not impair the emergency movement of occupants of the building or emergency personnel to an extent greater than that allowed by Sections 402 and 405 of the MPS [1, 2, 3, 4], NFPA 101 [21] and local codes.

Evaluation

Review of drawings and specifications.

Commentary

The location of solar equipment on a roof could reduce the usability of that roof for access or egress. Solar system components located remote from the building but near a means of egress could block the means of egress if a fire occurs in the solar system component.

4.5.2 Criterion

Identification and location of controls. Main shutoff valves and switches should be conspicuously marked and placed in locations that are readily accessible to those personnel who would normally be expected to operate them in the event of an emergency. These valves and switches shall be located in the same manner as specified in 240.24 of NFPA 70 [5] for electrical panels.

Evaluation

Review of drawings and specifications.

Commentary — In large buildings, accessibility would normally be limited to qualified personnel; however, in small buildings, accessibility to the tenants should be provided.

In addition, controls which should only be adjusted by skilled personnel should not be located in areas subjected to normal occupant access.

4.6 Requirement — Protection of potable water and circulated air. No material, form of construction, fixture, appurtenance or item of equipment shall be employed that will support the growth of micro-organisms or introduce toxic substances, impurities, bacteria or chemicals into potable water and air circulation systems in quantities sufficient to cause disease or harmful physiological effects.

4.6.1 Criterion — Contamination of potable water. Materials which come in direct contact with potable water shall not affect the taste, odor, or physical quality and appearance of the water in an undesirable manner.

Evaluation — Review of plans and specifications. The quality of the water shall be in compliance with the National Interim Primary Drinking Water Regulation [22].

Commentary — This criterion is not intended to preclude using dyes suitable for ingestion as a means for the detection and warning of leaks in the system.

4.6.2 Criterion — Separation of circulation loops. Circulation loops of subsystems utilizing non-potable heat transfer or thermal storage fluids shall either be separated from the potable water system in such a manner that a minimum of two physically separated walls or interfaces is maintained between the non-potable liquid and the potable water supply or otherwise protected in such a manner that equivalent safety is provided.

Evaluation — Review of drawings and specifications.

Commentary — Double wall heat exchanger designs are one way of meeting the intent of this criterion. When double wall heat exchanger designs consisting of two single wall heat exchangers in combination with an intermediary potable heat transfer liquid are used, leakage through one of the walls would result in a single wall configuration. Although this design is considered to meet the intent of this criterion, there are several other designs that avoid this problem.

The use of single wall configurations which solely rely upon potable water pressure to prevent contamination or extra thick single walls are examples of constructions which are not considered to meet the intent of this criterion.

When two walls are in intimate contact with one another, pitting initiated through one wall can readily continue through the other wall.

When available, an ASME solar energy standard for heat exchangers for heating and cooling, currently in preparation, will provide a consensus standard specifically tailored to solar applications.

4.6.3 Criterion

Identification of potable water and non-potable fluids. In systems where dual fluid subsystems, one potable water and the other non-potable fluid, are installed each shall be identified either by color marking or metal tags as required in ANSI A13.1-1956 [23] or other appropriate methods.

In systems which are designed for the use only of non-potable, non-toxic fluids, warning and description of such use restriction shall be provided at all system fill and drain points.

Evaluation

Review of drawings and specifications.

Commentary

Owner/occupants should be made aware that initially harmless fluids may degrade during use through decomposition or interaction with impurities in closed loop systems. There should be provisions for periodically monitoring the quality of these fluids to make owner/occupants aware of the potential for health hazard and corrosive action posed by such degraded fluids.

4.6.4 Criterion

Backflow prevention. Backflow of non-potable fluids into the potable water systems shall be prevented.

Evaluation

Review of drawings and specifications. Inspection of assembled systems.

Commentary

Pollution of the potable water supply can occur by way of backflow caused by back pressure and/or backsiphonage within a cross connection between the potable supply and non-potable fluid in the system. The former type of backflow can occur, for example, from elevated tanks or pumps. The latter can occur when the potable water supply system is under vacuum such as might occur with a broken street water main.

Piping arrangements, backflow prevention devices, and/or air gaps are commonly used to prevent contamination of potable water systems.

4.6.5 Criterion

Contamination of air. Materials which come in direct contact with air shall not affect the odor or biological quality of the air in an occupied space in an undesirable manner. Solar systems utilizing a heat source containing noxious fumes and serving an occupied area shall maintain a separation of the two streams in such a manner that leakage will not contaminate the air in the occupied space.

Evaluation

Review of drawings and specifications.

Commentary

Special consideration should be given to the presence of fungus, mold or mildew in air handling systems since such micro-organisms are often allergenic. Filtering of air streams may be desirable but such provisions in passive systems with low air velocities may be impractical. Rock containing asbestos should not be used due to the potential carcinogenic hazard. Cleanliness of the rock storage medium is further covered in section 2.4.2.

Protection of air in occupied spaces from noxious fumes may be accomplished by the use of suitable, non-corrodable heat exchangers which maintain an absolute pressure in the secondary side higher than in the primary side. An example of such an installation would be an ammonia heat pipe which exchanges heat directly to an air stream.

4.6.6 Criterion		Growth of fungi. Components and materials used in the H/C/HW systems that come in contact with air being supplied to an occupied area or with potable water and that operate under conditions that promote the growth of fungi, mold or mildew shall not support such growth.
	Evaluation	The materials shall be capable of withstanding exposure to fungus as defined by either Method 10 of UL 181 [24] or Appendix D, Section E of the MPS 4900.1 and 4910.1 [1, 2]. Review environmental and design operating conditions.
	Commentary	Fungi can feed on some organic materials and generally thrive in warm, moist environments. The potential for fungus growth in a rock storage container which becomes damp due to the failure of waterproofing membrane around the container or other causes could be a substantial problem requiring periodic maintenance. Use of a fungicide in such maintenance could introduce another potential airborne hazard and other methods may be preferable.
4.7	Requirement	Protection from physical hazards. The H/C/HW systems shall not create a hazard to people greater than those found in conventional buildings.
4.7.1	Criterion	Installation Arrangement. The location provided for solar components shall not increase the accident potential to a greater extent than would be expected for a conventional non-solar building.
	Evaluation	Review of calculations, drawings and specifications.
	Commentary	Some examples can be given of how the presence of solar components might increase accident potential: (1) reflected rays from the collector could be distracting to drivers on adjacent highways or annoying to the occupants of nearby buildings, and (2) the ground around a storage unit might settle, creating a hazard because of the uneven ground.
4.7.2	Criterion	Heated components. Subassemblies of the H/C/HW systems that are accessible, located in areas normally subjected to public traffic and which are maintained at elevated temperatures shall either be insulated to maintain their surface temperatures at or below 140°F at all times during their operation or be suitably isolated. Any other exposed areas that are maintained at hazardous temperatures shall be identified with appropriate warnings.
	Evaluation	Review of drawings and specifications.
4.7.3	Criterion	Snow and ice. In areas which have a snow load of 20 pounds per square foot or greater required by local codes, provisions should be made over entrances and locations of pedestrian and vehicular ways to restrain or deflect sliding snow and ice masses which may slide off elevated solar system components.
	Evaluation	Review of drawings and specifications.
	Commentary	Solar system components may often include smooth slippery surfaces located in elevated positions at steep angles. These elements may heat up rapidly and loosen masses of snow or ice which may slide off. Means should be provided to prevent a hazard to people or property. Methods such as deflectors, restraints, low friction materials, or design of "safe fall" areas (pedestrian or vehicular routes located away from the building) should be considered.

4.7.4 Criterion

Lightning protection. As applicable, lightning protection shall be provided in accordance with the NFPA No. 78 Lightning Protection Code [25].

Evaluation

Review of calculations, drawings, and specifications.

Commentary

There is some evidence to suggest that solar arrays, particularly solar arrays with plastic covers, increase the electrostatic potential between ground and air, and could induce increased lightning hazard in areas of high lightning incidence.

4.7.5 Criterion

Glazing Materials. Solar panels with slopes less than 45^{o} with the horizontal and which extend lower than 6 feet above a walking surface for unrestricted traffic adjacent to the panel shall be safety glazed or otherwise protected against impact of persons falling against the glazing. Panels with glazing materials meeting the impact and breakage requirements specified by the "Federal Mandatory Standard for Architectural Glazing Materials," 16 CFR Part 1201 [26], shall be considered safety glazed.

Glazing materials other than those specified above shall meet the intent of the requirements for glazing in MPS Section 508-8 [1, 2, 3].

Evaluation

Review compliance certification documents or test in accordance with procedures specified in "Federal Mandatory Standard for Architectural Glazing Materials" [26].

Commentary

These criteria are intended to reduce the risk of injuries to people from accidental contact with solar glazing materials. It is intended that they be applied to glazing materials in solar systems only in those areas where there is a likelihood that people might accidentally come in contact with the glazing, such as installations on which children might climb or against which a passerby may fall.

Traditionally, greenhouse type structures have been considered to provide adequate protection against the hazard of persons falling against them. It is not the intent of this criterion to impose new requirements on greenhouses of conventional design when used for solar applications.

Where large expanses of glazing are used, as in passive installations, the Federal safety standard for architectural glazing materials [26] should be reviewed for its applicability with respect to physical location and arrangement of the glazing and exposure risk of persons nearby.

Potential safety hazards should be considered in areas exposed to falling limbs or other projectiles with regard to installation of skylights, clearstory windows and collector arrays. Where safety glazing is not employed, consideration should be given to provisions to restrain or deflect broken glass which may slide off elevated solar system components over entrances and locations of pedestrian and vehicular traffic ways.

Film-type glazing materials for the outermost cover plates, if unsupported, may be unacceptable if they undergo large deflection under load, e.g. a person's hand pushing against the glazing, may present an opportunity for exposure of the film (and the person's hand) to hot surfaces such as the absorber plate, see Criterion 4.7.2.

References 4

1. HUD Minimum Property Standards, One and Two Family Dwellings, (No. 4900.1), U.S. Department of Housing and Urban Development, Washington, D.C. (1973, revised 1976).+

2. HUD Minimum Property Standards, Multifamily Housing, (No. 4910.1), U.S. Department of Housing and Urban Development, Washington, D.C. (1973, revised 1976).+

3. HUD Minimum Property Standards, Care-Type Housing, (No. 4920.1), U.S. Department of Housing and Urban Development, Washington, D.C. (1973, revised 1976).+

4. HUD Intermediate Minimum Property Standards Supplement, Solar Heating and Domestic Hot Water Systems, (No. 4930.2), U.S. Department of Housing and Urban Development, Washington, D.C. (1977).+

5. National Electric Code, NFPA, No. 70, 1978 (Also ANSI C1, 1978).

6. Flammable and Combustible Liquid Code, NFPA, No. 30, 1977.*

7. Clearances, Heat Producing Appliances, NFPA No. 89M, 1976.*

8. Air-Conditioning and Venting Systems, NFPA No. 90A, 1976.*

9. Warm Air Heating and Air Conditioning, NFPA No. 90B, 1976.*

10. Chimneys, Fireplaces and Vents, NFPA No. 211, 1977.*

11. Gas Appliances and Gas Piping Installation, NFPA No. 54, 1974* (also ANSI Z83.1, 1972).

12. Oil Burning Equipment, NFPA No. 31, 1974* (also ANSI Z95.1).

13. Fire Tests of Roof Coverings, NFPA No. 256, 1976* (also ASTM E108, 1975++, and UL 790).

14. Provisional Flat Plate Solar Collector Testing Procedures, First Revision, NBSIR 78-1305A, National Bureau of Standards, Washington, D.C., June 1978.

15. Surface Burning Characteristics of Building Materials, Test for, ASTM E84-77, 1977.++

16. Standard Methods of Fire Tests of Building Construction and Materials, NFPA No. 251, 1972* (also ASTM E119 and UL 263).

17. Flame Resistance Permanency, ASTM C739-73, Section 10.4, 1973.++

18. "Federal Hazardous Substances Act," Code of Federal Regulations (CFR) Title 16, Part 1500.+

19. Searcy, J. Q., ed., Hazardous Properties and Environmental Effects of Materials Used in Solar Heating and Cooling (SHAC) Technologies: Interim Handbook, SAND 78-0842, Sandia Laboratories, Albuquerque, N.M., June 1978.

20. Basic Classification of Flammable and Combustible Liquids, NFPA No. 321, 1976.*

21. Life Safety Code, NFPA No. 101, 1976.*

22. National Interim Primary Drinking Water Standards, 1977, Environmental Protection Agency, Office of Water Supply, Stock Number 055-000-00157-0.+

23. Scheme for the Identification of Piping Systems, ANSI A13.1, 1975, American National Standards Institute, 1430 Broadway, New York, N.Y. 10018.

24. Standard for Factory Made Air Duct Materials and Air Duct Connectors, UL 181, Underwriters Laboratories, 333 Pfingston Road, Northbrook, Ill. 60062, 1974.

25. Lightning Protection Code, NFPA No. 78, 1977.*

26. "Federal Mandatory Standard for Architectural Glazing Materials," 16 CFR 1201, Federal Register, January 6, 1977.+

27. Metz, F. E., and Orloski, M.J., "State-of-the-Art Study of Heat Exchangers Used With Solar Assisted Domestic Hot Water Systems," NBSIR 78-1542, July 1978.**

* National Fire Protection Association (NFPA), 470 Atlantic Avenue, Boston, MA 02210.

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5.1	Requirement	Effects of external environment. The H/C/HW systems, their various subassemblies and the building elements with which they interact shall not be affected by external environmental factors to an extent that will significantly impair their function during their design life.*
5.1.1	Criterion	Solar degradation. Components or materials shall not be adversely affected by exposure to sunlight in service to an extent that will significantly impair their function during their design life. When components or materials are exposed to UV radiation with or without an intermittent water spray at their maximum service temperature, there shall be no signs of excessive deterioration such as cracking, crazing, embrittlement, etching, loss of transmittance, loss of adhesion, changes in permeability, loss in flexural strength, or any other changes that would significantly affect the performance of the components in the system.
	Evaluation	Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. Where adequate information is unavailable, testing using either the methodology outlined in Section 2 of Appendix 3 or other methods which can be shown to meet the intent of the criterion shall be used.
	Commentary	Some organic materials which may be used in the system may be particularly susceptible to solar degradation under prolonged exposure. Components of particular concern include cover plates (including films and coatings), absorber surfaces, collector heat traps, collector insulation, outdoor exposed insulation and its coatings, control insulation (shutters, shades, drapes, blinds, etc.) and reflectors. Care should be taken that coated cover plates that have a weather side are properly installed. Some glazings are designed to be recoated after a period of time due to weathering of the surface. Transmittance of cover plates and emittance, and absorptance data of absorber material are required to estimate the effects of degradation by solar radiation in reducing collector efficiency.
5.1.2	Criterion	Moisture. Solar components, materials and the building elements with which they interact shall not be adversely affected by exposure to moisture in service to an extent that will significantly impair their function during their design life. Means shall be provided to prevent the penetration of water into collectors, other solar hardware components and building elements.
	Evaluation	Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. Where adequate information is unavailable, methods which can be shown to meet the intent of the criterion shall be used. A provisional test described in test method 7.5 of NBSIR 78-1305A [1] is one means of assessing rain penetration into solar collectors.

*Information concerning the properties of materials for solar applications is given in Section 12 of Appendix 3.

Commentary

Moisture can exhibit itself in several forms, e.g., rainfall, melting snow and ice, or condensation. The intent of this criterion is to ensure adequate performance of components or materials that are expected to be exposed to moisture in service. Some components, such as collector insulation, are usually intended to be used in low moisture environments; however, it is still possible for them to be periodically exposed to moisture from condensation. Such components would not usually be expected to meet the intent of this criterion if moisture exposure could not occur, e.g., in collectors that are hermetically sealed. If flat plate collectors are not hermetically sealed, the likelihood of condensation forming on the underside of the cover plates or absorber surfaces is quite high. Desiccants in breather tubes or plugs can be used to aid in the prevention of condensation. The desiccants should be located in such a way that they are not in contact with the collector plate and it is desirable that they be capable of regeneration by solar energy as collector temperatures increase.

A potential problem with collectors which are not hermetically sealed is that, in industrial atmospheres, pollutants in condensate solution may cause permanent etching of the underside of the cover plates and absorber surfaces over a period of time. Such etching can permanently reduce transmittance or absorptance. When this possible condition exists, design consideration must be given to avoid the problem.

The presence of moisture in rock storage bins due either to penetration of bin walls or the hygroscopic characteristics of the rock itself can lead to adverse effects of thermal performance (loss of energy in latent heat form) as well as moisture induced deterioration of the container and the growth of fungus (see Section 4.6.5).

Water leakage can occur with double glazed collectors such that the space between the cover plates receives the leakage but not the inner portion of the collector. Although this may not significantly reduce solar transmission it increases collector losses, is subject to freezing and may have other detrimental effects.

The build up of moisture in building elements caused by the presence of solar system components can result in the rotting of materials and the growth of mold and fungus. More specifically, there is a high potential for fungus growth occurring under collectors that are applied over a building watertight membrane and it may be possible for fungi to grow on both the interior and exterior of collector components leading to deterioration of absorber surfaces and the creation of corrosion supportive conditions which may affect collector performance. The provision of adequate ventilation may be desirable.

Guidance for the waterproofing of exposed insulation both above and below ground is given in the HUD MPS section 607-2 [2], and also the ASHRAE Handbook of Fundamentals Chapter 17 [3].

5.1.3 Criterion

Ice dams and snow build up. The design of solar buildings and systems shall provide for the possibility of the formation of ice dams and snow build up.

Evaluation

Review of drawings and specifications.

Commentary — In very cold climates, water flowing off a warm collector may freeze on cold surfaces immediately below it (such as exposed eaves), thereby forming an ice dam which can cause water to back up under roofing or into the collector itself. This may be moderated by methods such as elimination of the cold surface or provision of an imprevious surface such as continuous flashing. Snow sliding off a collector may pile up at the bottom and cover part of the collector. This would have a tendence to reduce the efficiency of the collector and increase the possibliity of thermal breakage of glass in the collector. This may be moderated by methods such as the provision of space below the collector for snow pile up or by the installation of heating cables.

A potential problem is the blockage of collector breathing tubes which can lead to pressure build up and consequent cover plate breakage.

5.1.4 Criterion — Soil related degradation. Solar components and materials that are intended to be buried in soils shall not degrade under in-use conditions to an extent that their function will be impaired during their design life.

Evaluation — Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. Where adequate information is unavailable, testing using either the methodology outlined in Section 3 of Appendix 3 or other methods which can be shown to meet the intent of the criterion shall be used.

Commentary — This criterion is primarily intended to protect metallic components from soil corrosion. It may be possible to protect some metallic components with the use of sacrificial anodes. Other components such as wood or plastics may also be degraded by contact with soil.

5.1.5 Criterion — Airborne pollutants. Solar components and materials that are exposed to airborne pollutants such as ozone, salt spray, SO_2 or NO_x shall not be adversely affected by these factors to the extent that will significantly impair their function during their design life.

Evaluation — Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. Where adequate information is unavailable, testing using either the methodology outlined in Section 4 of Appendix 3 or other methods which can be shown to meet the intent of the criterion shall be used.

The maximum pollutant levels in the areas where the system will be installed shall be used to determine the pollutant levels required for testing. If components are to be used in areas where they are not exposed to any or all of these pollutants, tests that are not applicable need not be conducted.

Commentary — Ozone concentrations in normal dry air have been reported to range from 1 - 5 pphm/volume. However, concentrations of 100 pphm/volume have been reported during very smoggy conditions. Ozone is known to degrade some organic materials but it has little effect on inorganic materials other than metals.

The effects of solar radiation in combination with airborne pollutants may also be an important consideration in the dry condition or in the presence of moisture. Factors of concern include surface erosion and consequent transmission loss of cover plate, deterioration of coupling hoses and exposed seals and corrosion of metallic elements.

5.1.6 Criterion

Dirt retention and staining. The collector cover plate and absorber surfaces shall not collect and retain dirt or stain to an extent that would significantly impair the function of the collector during its design life.

Evaluation

Engineering analysis, documentation of satisfactory long-term performance under in-use conditions and review of plans and specifications.

Commentary

The possible collection and retention of dirt and stains by the cover plate and the effect of this on the collector performance may be significant. The retention of dirt may be affected by the tilt angle of the collector. Rainfall and snow melt are generally sufficient to keep the cover plates clean on the outside. In areas of low rainfall or because of the nature of the cover plate surface, periodic washing may be required to remove dirt and stain. Accumulations of sap, leaves, branches, etc., can also degrade collector performance.

In air collectors another problem may be significant, performance reduction due to internal dirt accumulation from the system. In some collectors air flow is through absorber material and is contained by a cover plate. In such circumstances normal dirt build up from air drawn from occupied spaces could cause a deterioration of heat transfer ability and spectral properties of the absorber. High temperatures could bake on such deposits. Filtering of such air flow may be desirable. A similar situation may exist in passive systems with air circulation (Trombé walls, air thermosyphons, etc.) where dirt deposits may occur on absorber or cover plate surfaces. Because of the low air velocities involved, filtration may be impractical and access for cleaning should be considered.

Abrasive wear is expected to present a possible problem in areas subject to wind driven dirt and sand. Also, abrasive wear of cover plates resulting from periodic cleaning or scrubbing may have a significant effect on the ability of the cover plates to transmit sunlight.

5.1.7 Criterion

Fluttering by wind. Solar components and materials that are subject to fluttering by wind shall not degrade under in-use conditions to an extent that will significantly impair their function during their design life.

Evaluation

Documentation of satisfactory long-term performance under in-use conditions, engineering analysis, or testing using an experimental verification procedure which can be shown to meet the intent of the criterion.

Commentary

Thin films that increase in brittleness at low temperatures may be particularly susceptible to degradation by fluttering by wind.

5.2 Requirement

Temperature and pressure resistance. Solar components, materials, and building elements with which they interact shall be capable of performing their intended function for their design life when exposed to the temperatures and pressures that can be developed in the system.*

*Maximum and minimum service temperatures are defined in Section 1 of Appendix 3.

5.2.1 Criterion

Thermal degradation, shock, and cycling stresses. Solar components materials, and building elements with which they interact shall not thermally degrade to the extent that their function will be reduced below design levels during their design life when exposed to maximum and minimum service temperatures and pressures.

Solar components and materials shall be capable of withstanding the stresses induced by thermal shock for their respective design lives.

The H/C/HW systems, their various subassemblies, and building elements with which they interact shall be capable of withstanding the stresses induced by thermal cycling for their respective design lives.

Evaluation

Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. When adequate information is unavailable for collector components, the "no-flow" aging procedure described in test method 7.2 of NBSIR 78-1305A [1] shall be used to evaluate thermal degradation. When adequate information for other components is unavailable, testing using either the methodology outlined in Section 5 of Appendix 3 or the methods which can be shown to meet the intent of the criterion shall be used to evaluate thermal degradation.

Provisional tests described in test method 7.3 (thermal shock/water spray) and 7.4 (thermal shock/cold fill) of NBSIR 78-1305A [1] are means of assessing the effects of thermal shock on collectors.

A provisional test described in test method 7.6 of NBSIR 78-1305A [1] is one means of assessing the effects of thermal cycling stresses on collectors.

Physical restraints (including support conditions) that will be imposed on the system in actual use shall be considered when testing is required.

Commentary

Some organic components which may be used in the system may be particularly susceptible to thermal degradation under prolonged exposure. Organic collector components of particular concern include cover plates, absorbers, absorptive coatings, heat traps, insulation, sealants, and enclosure frames. Storage containers, piping, liners and coatings composed or organic materials are also components of particular concern.

Another concern is the use, in rock bed thermal storage, of rocks that dust when exposed to in-use temperatures due to decomposition.

Heat from collectors and other solar components can cause the premature thermal degradation of adjacent building elements. This degradation may be enhanced by the presence of moisture.

In addition to evaluating thermal degradation, this criterion is intended to identify potential problems that may occur as a result of differential thermal movement. Thermal compatiblity is especially critical in the case of collectors which may contain large expanses of glazing. If thermal expansion is cumulative in system or subsystem design, the test must be designed to reflect this condition. Areas of concern include cover plate/frame, collector/support, collector/collector, collector/piping, reflective surface/substrate, piping, coupling hoses, sensors, the bond of tube or coatings to absorber plate and warping or shrinkage of cover plate or absorber.

5.2.2 Criterion

Deterioration of fluids or phase change materials. Except when such changes are allowed by the design of the system, fluids or phase change materials shall not freeze, give rise to excessive precipitation, otherwise lose its homogeneity, boil, change absorptivity or change pH or viscosity beyond the design ranges when exposed to their maximum and minimum service temperature and pressure during their design life.

Evaluation

Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. Where adequate information is unavailable, testing using either the methodology outlined in Section 6 of Appendix 3 or other methods which can be shown to meet the intent of the criterion shall be used.

Commentary

Although boiling can be prevented by pressurization, excessive temperatures can break down some constituents of the fluid to form organic acids. Buffers can counter the pH balance but only until they are exhausted. Changes in pH can be accepted but when the allowable range is exceeded, the transfer fluid or at least the buffers must be renewed. This can be an acceptable maintenance requirement.

Thermal cycling may cause precipitation to occur which may lead to a build up of solids in pump seals and valve seats which may lead to malfunction.

Viscosity changes in heat transfer fluids may lead to pumping problems, if not considered in the design such as excessive pumping power requirements or overheating due to heat transfer fluid thickening.

When heat transfer fluids are used as absorbers a bleaching of the fluid may significantly reduce system performance.

Standardized methods to evaluate the durability of phase change thermal storage materials due to temperature cycling have not been developed. Evidence of the ability of a phase change material to remain stable through a number of cycles representative of a specified portion of its design life would be useful.

5.2.3 Criterion

Outgassing. Outgassing of volatiles that will reduce collector performance below specified design values shall not occur when the collector is exposed to the maximum service temperature and pressure.

Evaluation

Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. Where adequate information is unavailable a provisional test described in test method 7.2 of NBSIR 78-1305A [1] or a test method described in Appendix D of NBSIR 77-1437 [4] or other methods which can be shown to meet the intent of the criterion may be used.

Commentary

If the results of the no-flow test procedure (procedures 7.2 of NBSIR 78-1305A [1]) indicate an outgassing problem then the test procedure outlined in Appendix D of NBSIR 77-1437 [4] may be used to evaluate components of the collector to determine which component(s) is at fault.

Outgassing from components inside the collector could lead to deposits on the underside of the collector cover plates reducing cover plate transmissivity or other changes in the optical properties of collector components.

Material problems that have been observed in the field include the outgassing of gaskets and sealants, absorptive coatings, and insulation.

5.3 Requirement

Chemical compatibility of components. Materials used in the solar system, its various subassemblies and the building elements with which they interact shall have sufficient chemical compatibility to prevent corrosive wear and deterioration that would significantly shorten their intended service life under in-use conditions.

5.3.1 Criterion

Deterioration of gaskets, sealants, and polymeric coupling hoses. Gaskets, sealants, and polymeric coupling hoses either dry or in direct contact with fluids shall not be adversely affected by contact with these fluids to an extent that will significantly impair their ability to function during their design life.

Evaluation

Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. Acceptability of gaskets and sealants shall be determined by the methods outlined in ASTM D 3667-78 [5] and in Appendix B and C of NBSIR 77-1437 [4]. Where adequate information is unavailable, coupling hoses may be tested using either the methodology outlined in Section 7 of Appendix 3 or other methods which can be shown to meet the intent of the criterion.

Commentary

Gaskets, sealants, polymeric coupling hoses, and similar organic materials frequently swell when exposed to liquids and, thus, may lose their ability to function.

The joints near coupling hoses are a potential source of leakage. The selection of coupling hoses and clamps is quite critical. Many failures have been noted due to the clamping of hoses with screw or spring-type clamps, exposing the hose to high temperatures which tend to harden the hose beneath the clamp, causing it to lose resiliency and begin to leak. Further tightening of the clamps will temporarily stop leakage but further hardening will occur with the end result being a hard non-resilient ring under the clamp which can no longer be tightened to prevent leakage. Silicone rubber hoses and EPDM's, if properly vulcanized, tend to maintain their resiliency with no tendency to take a thermal set. The silicone rubber hoses, however, tend to be so pliable that screw-type clamps with perforated bands should not be used as it is possible to extrude the material through the perforations in the band. If this material is used, smooth band clamps should be utilized.

5.3.2 Criterion

Materials/transfer fluid compatibility. Materials designed to be used in contact with heat transfer fluids shall not be corroded or otherwise adversely affected by these fluids to the extent that their function will be significantly impaired under in-use conditions during their design life.

Evaluation

Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. Acceptability of gaskets and sealants shall be determined by the methods outlined in Appendix B of NBSIR 77-1437 [4]. Where adequate information is unavailable, materials may be tested using the methodology outlined in Section 8 of Appendix 3 or other methods which can be shown to meet the intent of the criterion.

Commentary

Corrosion of metals by heat transfer fluids could be a serious problem in solar energy systems. Society of Automotive Engineers (SAE)* Standard J447a (1964), "Prevention of Corrosion of Metals," provides guidance in preventing corrosion. Experience indicates that tight closed loop systems help to prevent corrosion.

Any use of inhibitors should be keyed to the characteristics of all elements of the energy transport system to which it is exposed including collectors, piping, connectors, tanks, pumps, valves, heat exchangers, etc. With non-toxic heat transfer fluids, any inhibitors should be selected to maintain the desired fluid properties, see section 4.4.1. Further discussion is included in reference [6].

5.3.3 Criterion

Compatability of dissimilar materials. Non-isolated dissimilar materials shall not be degraded to the extent that their function will be significantly impaired under in-use conditions during their design life.

Evaluation

Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. Where adequate information is unavailable, testing using either the methodology outlined in Section 9 of Appendix 3 or other methods which can be shown to meet the intent of the criterion shall be used. Dissimilar materials used in contact with heat transfer or other fluids shall be tested to reflect this condition. Where protective finishes are normally provided they shall be used on the specimens tested.

Commentary

The use of corrosion inhibitors or dielectric fittings that electrically isolate dissimlar materials may be desirable. In the case of plastics, plasticizer migration may be a concern. The presence of pinholes in protective coatings may drastically accelerate corrosive action.

Attention should be paid to all elements of a solar system when considering compatibility of dissimilar materials. This should include energy transport system, structural support and connections, fabricated parts, and roofing materials.

5.3.4 Criterion

Corrosion by leachable substances. Chemical substances that can be leached by moisture from any of the materials within the system shall not cause corrosive deterioration of solar components or building elements that would significantly impair their ability to perform their intended function over their design life.

Evaluation

Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. Where adequate information is unavailable, testing using either the methodology outlined in Section 10 of Appendix 3 or other methods which can be shown to meet the intent of the criterion shall be used.

Commentary

Salts such as those that can be leached by moisture from some types of glass fiber and mineral wool insulation or from ogranic components may cause corrosion of system components that are in close proximity. Chlorides or sulfates that may be leached are of particular concern in regard to metallic corrosion. Corrosion of solar components can also be caused by substances leached from roofing materials.

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5.3.5 Criterion

Effects of decomposition products. Chemical decomposition products that are expelled from solar components or building elements under in-use conditions shall not cause the degradation of solar components or building elements to the extent that would significantly impair their ability to perform their intended function over their design life.

Evaluation

Documentation of satisfactory long-term performance under in-use conditions or engineering analysis. Where adequate information is unavailable, testing using either the methodology outlined in Section 11 of Appendix 3 or other methods which can be shown to meet the intent of the criterion shall be used.

Commentary

Components and materials, such as gaskets, sealants, coatings, etc., may yield degradation products during their service life without impairing their function or aesthetic properties. These degradation products could significantly impair the performance of other components in the system.

Heat transfer fluids, including inhibited water, may decompose and cause scale build up which may cause deterioration of performance. This is particularly true of hot water heaters where supply water is heated directly in the collector and dissolved solids (calcium salts) precipitate.

5.4 Requirement

Components involving moving parts. Components that involve moving parts shall, with normal maintenance, be capable of performing their intended function without excessive wear or deterioration for their design life.

5.4.1 Criterion

Wear and fatigue. Check valves, pressure regulators, pumps, electrical switches, collector tracking mechanisms, insulation movement mechanisms and assemblies, and similar components shall be capable of operating under in-use conditions for their intended life spans without exhibiting wear or fatigue that would reduce their performance below specified levels.

Evaluation

Documentation of satisfactory long-term performance under in-use conditions, engineering analysis, or testing using an experimental verification procedure which can be shown to meet the intent of the criterion. Either the number of cycles that would be expected in actual service under in-use conditions or an accelerated procedure shall be used for experimental verification.

Commentary

Inclusion of the heat transfer fluid during tests of components with moving parts may be helpful. In particular, very hard crystalline precipitates may be formed from some types of heat transfer fluids and their additives.

Many of the components described in the criteria involve the use of conventional components in unusual applications. A record of satisfactory performance in the conventional application may not be sufficient to adequately predict performance in the solar application and careful evaluation may be desirable.

In some applications, less expensive components which are easily replaced but have shorter expected lifespans may be more desirable than more reliable but more costly components.

References 5

1. Provisional Flat Plate Solar Collector Testing Procedures, First Revision, NBSIR 78-1305A, National Bureau of Standards, Washington, D.C., June 1978.

2. HUD Minimum Property Standards, One and Two Family Dwelling, (No. 4900.1), U.S. Department of Housing and Urban Development, Washington, D.C. (1973, revised 1976). +

3. ASHRAE Handbook of Fundamentals - 1977.*

4. Solar Energy Systems - Standards for Rubber Seals, NBSIR 77-1437, National Bureau of Standards, Washington, D.C., March 1978.**

5. Standard Specification for Rubber Seals Used in Flat Plate Solar Collectors, ASTM D 3667-78 1978.++

6. Metz, F.E., and Orloski, M.J., "State-of-the Art Study of Heat Exchangers Used with Solar Assisted Domestic Hot Water Systems, NBSIR 78-1542, July 1978.**

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6.1	Requirement	Maintenance and servicing. The H/C/HW systems shall be designed, constructed and installed to provide sufficient access and appurtenances for general maintenance, convenient servicing, and monitoring of system performance.
6.1.1	Criterion	Access for system maintenance. All individual items of equipment and components of the H/C/HW systems which may require periodic examination, adjusting, servicing and/or maintenance shall be accessible for inspection, service, repair, removal or replacement without dismantling of any adjoining major piece of equipment or subsystem, or building element. Individual collectors in an array shall be replaceable or repairable without disturbing non-adjacent collectors in the array.
	Evaluation	Review of drawings and specifications.
	Commentary	Accessibility as a function of component life is an important consideration. Some manufactured collector systems and many individually designed systems are done in such a way that sequential installation is necessary. This can make it very difficult to replace an individual collector without disturbing the entire array. Access to storage units may be necessary. Rock storage and liquid storage in both active and passive systems may require access for cleaning or replacement. Collector glazings which require periodic recoating will need access. Isolation valves may be necessary for the repair or replacement of system components. Information on access provisions is provided in Reference [1].
6.1.2	Criterion	Misuse. Solar components shall be located where the potential for their misuse is minimized.
	Evaluation	Review of building plans indicating occupant access and site plans showing the location of recreational facilities, protective screening, roads, sidewalks, and solar subsystems.
	Commentary	The proximity of system components to playgrounds and sidewalks should be examined to minimize potential misuse or vandalism.
6.1.3	Criterion	Draining and filling of fluids. To facilitate system or subsystem maintenance and repair, subsystems employing fluids shall be capable of being filled and drained by appropriate personnel.
	Evaluation	Review of drawings, specifications, and maintenance instructions.
	Commentary	In systems employing hazardous fluids it may be desirable to arrange drain and fill provisions so that this work may be accomplished only by skilled maintenance personnel using appropriate equipment. An example of this would be domestic hot water systems using an ethylene glycol/water mixture for the heat transfer fluid.
6.1.4	Criterion	Flushing of liquid subsystems. Suitable connections shall be provided for the flushing (cleaning) of liquid energy transport subsystems.
	Evaluation	Review of drawings and specifications.
	Commentary	The recommendations of the system manufacturer for cleaning agents compatible with the materials of the system should be followed.

6.1.5	Criterion	Filters. Filters shall be designed and located so that they can be cleaned or replaced with minimum disruption to the system and adjacent equipment. Cleaning frequencies shall be specified by the system manufacturer in the maintenance manual.
	Evaluation	Review of drawings and specifications.
6.1.6	Criterion	Water shut off. The HW system shall be valved to shut off from the cold water supply.
	Evaluation	Review of drawings and specifications.
6.1.7	Criterion	Impairment of operation. The functional capability of the H/C/HW systems shall not be impaired to a greater extent than conventional systems when system repairs or modifications are being made.
	Evaluation	Engineering review of specifications and drawings.
	Commentary	Equipment that requires preventive maintenance shall be provided with complete instructions to maintain proper and efficient operation of component, subsystem, and system.
6.1.8	Criterion	Permanent maintenance accessories. Permanent maintenance accessories such as hose bibs, drains, and ladder supports necessary for the maintenance of the H/C/HW systems shall be provided.
	Evaluation	Review of maintenance plans and drawings and specifications showing type and the location of drains, walkways, ladder supports, safety belt slips, and other permanent maintenance accessories relative to the location of solar equipment.
	Commentary	Drains, hose bibs, and surfaces for supporting ladders or other equipment may be needed to service the solar equipment.
6.1.9	Criterion	Protection. Protection shall be provided for the system during maintenance in accordance with manufacturers instructions.
	Evaluation	Review of maintenance manual.
	Commentary	System may require special protective measures during shut-down for maintenance such as protection for collectors or controls.
6.2	Requirement	Installation, operation and maintenance manual. A manual shall be provided containing instructions for the installation, operation, and maintenance of the H/C/HW systems and/or subsystems, and components.
	Commentary	This manual may consist in whole or in part of a series of instruction sheets provided by the various subsystem and component manufacturers. It may be a single manual, or installation instructions may be separate from operation and maintenance. Its size and complexity should be consistent with the need for descriptive information. The simplest passive system may warrant no more than an attached label or tag.

6.2.1 Criterion

Installation instructions. The instructions shall include physical, functional, and procedural requirements for H/C/HW subassembly and component installation.

These instructions shall describe the interconnection requirements of the various subsystems and components and their interface requirements with the building and site.

The instructions shall be available at the installation site or from normally accessable sources.

Evaluation

Review of installation instructions.

Commentary

It is not the intent of this criterion to require the provision of complete, detailed system installation specifications. Such specifications would normally be project specific and part of the procurement process.

6.2.2 Criterion

Maintenance and operation instructions. The manual shall describe the H/C/HW systems, their breakdown into subsystems, their relationship to external systems and elements, their performance characteristics, and their required parts and procedures for meeting specified capabilities.

The manual shall list all parts of the system, by subsystem, describing as necessary for clear understanding of operation, maintenance, repair, and replacement, such characteristics as shapes, dimensions, materials, weights, functions, and performance characteristics. The manual shall include sequence of operation, flow diagrams, and wiring diagrams. The manual shall include a tabulation of those specific performance requirements which are dependent upon specific maintenance procedures. The maintenance procedures, including ordinary, preventive and minor repairs, shall be cross-referenced for all subsystems and organized into a maintenance schedule. The manual shall describe operation procedures for all parts of the system including those required for implementation of specified planned changes in mode of operation.

The manual should specify temperature, pressure, and flow conditions which are expected to occur at the access points required in Criterion 6.4.2 to facilitate operational checks and troubleshooting.

The manual shall describe start-up and shutdown procedures.

Evaluation

Review of maintenance and operating instructions.

Commentary

One of the most common sources of malfunction in large systems is expected to be in the control subsystem. These malfunctions are not always complete failures but more often a matter of adjustment. Control subsystem malfunctions are not usually obvious unless testing at specified points is conducted.

For package systems, it would be desirable to have start-up and shutdown procedures indicated on a simple label.

6.2.3 Criterion

Maintenance plan. The manual shall include a comprehensive plan for maintaining the specified performance of the H/C/HW systems for their design service lives.

The plan shall include all the necessary ordinary maintenance, preventive maintenance and minor repair work, and projections for equipment replacement.

	Evaluation	Review of maintenance plan.
	Commentary	This criterion is applicable to both active and passive systems.
6.2.4	Criterion	Replacement parts. Parts, components, and equipment required for service, repair, or replacement shall be commercially available from the system or subsystem manufacturer or supplier.
	Evaluation	Review of specifications for the availability of parts.
	Commentary	This criterion is intended to preclude long periods of system downtime due to the need for the repair or replacement of parts. It would be desirable to have a minimum one-year's supply of consumable parts and potential early failure items, such as fan belts, bearings, etc., available for the system.
6.2.5	Criterion	Maintenance hazards. The manual shall provide warning against hazards that could arise in the operation and/or maintenance of the system and shall fully describe the precautions that shall be taken to avoid these hazards.
	Evaluation	Review of maintenance and operating instructions.
	Commentary	Some systems contain toxic and/or combustible materials that could result in the poisoning of maintenance personnel or result in fires or explosions when repairs involving soldering or welding are involved. In addition, toxic fumes can be given off. Indications of hot valves and discharge points should be given.
6.3	Requirement	Repair and service personnel. The H/C/HW systems shall be designed in such a manner that they can be conveniently repaired by qualified service personnel.
6.3.1	Criterion	Servicing of H, C, HC and HW systems. The H, C, HC and HW systems shall be capable of being serviced with a minimum amount of special equipment by the appropriate existing trades (HVAC, plumbing, etc.) using a service manual.
	Evaluation	Review of drawings, specifications, and service instruction manuals.
	Commentary	The complexity and design of certain components may require their removal and replacement for repair of the system.
6.4	Requirement	System monitoring. Provision shall be made for system monitoring in accordance with the specifications of the installation, operation and maintenance manual.
6.4.1	Criterion	Minimum operating information. Provisions shall be made to indicate to the user when either the collector loop or the auxiliary energy system is operating.
	Evaluation	Review of drawings, specifications and operating instructions.
	Commentary	A minimum level of information is essential to the user to assure that the solar system is functioning as intended. Monitoring means may involve sensor and indicators or they may be as simple as observation and awareness of appropriate radiant temperatures and air movement.

6.4.2	Criterion	Access for system monitoring. Appropriate access for sensors shall be provided for inspecting and checking essential system parameters, e.g. temperature, pressure and critical voltages.
	Evaluation	Review of drawings and specifications for the location of test fittings and electrical contacts.
	Commentary	Adequately located test fittings will permit system monitoring and expedite the maintenance and repair of equipment.

References 6

1) Uniform Mechanical Code, International Conference of Building Officials, 5360 South Workman Mill Road, Whittier, California 90601, 1973.

(Note: This chapter has resulted from the consolidation of chapters 7-13 of "Interim Performance Criteria for Solar Heating and Combined Heating/Cooling Systems and Dwellings," Jan. 1975.)

7.1 Requirement

Thermal design. The building and site shall utilize materials, designs, and construction methods appropriate for their intended use.

7.1.1 Criterion

Energy conservation. The dwelling total energy usage including factors related to microclimate, site, exterior envelope, illumination, H/C energy distribution, and HW shall be designed for overall efficiency including use of solar energy.

The dwelling design shall take into account the interaction between dwelling energy usage and the solar energy system.

Evaluation

Review of calculations, drawings, and specifications.

Commentary

A well designed solar energy system should include a building which is energy conserving since collector area and sizing of other solar hardware components is proportional to the building load requirements. ASHRAE Standard 90-75 [1] sets forth requirements for the design of the exterior envelope of new buildings for effective use of energy. Insulation to levels greater than those specified in 90-75 is normally desirable in solar buildings to minimize heating load. In the case of passive buildings it may be desirable to tailor the design to the optimum use of glazed areas, thermal mass, insulation, ventilation and other appurtenances for heating, cooling and illumination. In such cases, the provisions of Section 10 (Energy Requirements for Building Designs Based on Systems Analysis) and 11 (Requirements for Buildings Utilizing Solar, Wind or Non-Depleting Energy Sources) of 90-75 may be applied.

There are several aspects that may be considered in the design of buildings that conserve energy. One consideration is site design where building energy consumption can be conserved by managing the microclimate and, therefore, modifying its effect on the building, for example, wind deflection. For a study identifying climate design regions and their impact on residential design, see reference [2]. A second consideration is the exterior envelope of the building where energy can be conserved by modifying factors such as: color, thermal conductivity, orientation, shading, surface area and weather tightness. A third consideration is the mass of the building which can exert considerable influence on the building's thermal behavior. A fourth consideration is space planning. For example, placing residential living areas on the south side and storage or corridor areas on the north, coordinate space use with natural temperature variations. Which combination of options is chosen and how effective the selection will be is dependent on design conditions and design goals.

7.2 Requirement

Functioning of building and site. The use and habitability of the building and site shall not be substantially impaired by the H/C/HW systems.

7.2.1 Criterion

Space use. A location shall be provided for solar subsystems that will not significantly impair the use of required exterior or interior spaces.

Evaluation

Review of site and building drawings showing the location of solar subsystems.

Commentary — The space provided for the solar subsystems should be in addition to that normally required. Solar subsystems should not reduce or increase humidity, temperature, or radiation beyond acceptable levels or interfere with required headroom or circulation space. Heat storage areas that are incorporated within the building should be properly insulated to prevent undesirable overheating of adjacent rooms. System subassemblies located on the site (e.g., collector or storage units) should not unduly interfere with trash removal, furniture moving, the servicing of mechanical equipment, or the normal movement of people and vehicles. The operation of solar equipment should not create noise levels which would impair the comfort levels of occupied spaces during the day or at night. Since a collector may reflect a large percentage of the incident solar radiation at high incidence angles, the possibility of reflecting solar rays onto areas where people congregate should be investigated. Solar subsystems such as storage should be used as positive design elements that add to rather than subtract from the aesthetic quality of a space.

7.2.2 Criterion — Impact on environment. A site location shall be provided for the solar subsystems which will not significantly degrade the immediate natural environment and site.

Evaluation — Review of drawings and a report on the negative effects of the building and its solar subsystems on drainage, vegetation, microclimate, and wildlife.

Commentary — This criterion does not require that existing conditions should be maintained but that environmental degradation of the site and the immediate area around the site should be prevented if it cannot be healed naturally without further deterioration. Several examples can be cited that could cause such conditions to exist: (1) if runoff from a large collector is not collected and carried away in a drainage system it could, for certain soil conditions, cause excessive erosion, (2) if the reflected rays from a collector or the shade created by a collector killed existing vegetation and prevented the growth of new vegetation, large areas of soil might be exposed to excessive runoff, and (3) if the installation of solar equipment is poorly planned or implemented, it can result in the unnecessary cutting down of trees or in other conditions which would kill vegetation such as compaction, sunburn, drying, grade change, root pruning, or lack of support.

7.2.3 Criterion — Interaction. The interaction of building and site with solar systems and components shall be in accordance with applicable criteria of Chapter 1.

Commentary — Applicable criteria include: 1.1.1, 1.1.2, 1.1.3, 1.2.1, 1.3.2, 1.4.2, 1.5.1, 1.6.2, 1.7.4, 1.8.1, and 1.8.2.

7.3 Requirement — Mechanical and electrical functioning of building and site. The mecahnical and electrical operation of the building or site shall not be adversely affected by the H/C/HW systems.

7.3.1 Criterion — Interaction. The interaction of building and site with solar systems and components shall be in accordance with applicable criteria of Chapter 2.

Commentary — Applicable criteria include 2.1.3, 2.1.7, 2.1.8, 2.1.9, 2.1.11 thru 2.1.17, 2.2.2, 2.2.3, 2.3.1, 2.3.2, 2.4.1, 2.4.2, and 2.5.1.

7.4	Requirement	Structural safety and serviceability of building and site elements. The structural safety and serviceability of building and site shall not be impaired by the H/C/HW systems.
7.4.1	Criterion	Loads. Building and site elements shall be capable of carrying the increased loads imposed by solar components.
	Evaluation	Review of structural drawings, specifications, and design calculations taking into consideration the loads set forth in Chapter 3, Structural.
	Commentary	All possible loading conditions, such as those created by thermal distortion, empty storage tanks exposed to wind or hydrostatic forces, alternate or adjacent span loading of panels, or combinations of live and dead loads should be checked. The addition of solar components to an existing structure may require detailed investigation of the existing structure and shall be based on the latest engineering practices and applicable codes.
7.4.2	Criterion	Penetration of structural members. When penetrations are required in structural members to accommodate passage of solar components, those structural members shall be designed so that compliance with the MPS is maintained.
	Evaluation	Review of structural and mechanical drawings.
	Commentary	This criterion is intended to prevent holes which are cut for the installation of pipes, ducts, conduit wires, and other mechanical equipment from reducing the required strength of structural members.
7.5	Requirement	Safety of building and site. The safe operation of the building or site shall not be affected by the H/C/HW systems.
7.5.1	Criterion	Protection from thermal deterioration. Building materials adjacent to solar equipment shall not be exposed to elevated temperatures that result in adverse physical, chemical, mechanical, or thermal changes that result in the creation of a safety hazard.
	Evaluation	Review of calculations, drawings, and specifications.
	Commentary	Building materials exposed to elevated temperatures may be subject to hardening, softening, melting, blistering, buckling, and other adverse changes which may reduce the structural and/or fire resistance ratings of the building elements.
7.5.2	Criterion	Interaction. The interaction of building and site with solar systems and components shall be in accordance with applicable criteria of Chapter 4.
	Commentary	Applicable criteria include: 4.1.1, 4.1.2, 4.2.2 thru 4.3.7, 4.4.2, 4.4.4, 4.4.5, 4.4.6, 4.5.1, 4.5.2, 4.6.1 thru 4.6.5, and 4.7.1 thru 4.7.5.

7.6	Requirement	<u>Durability and reliability of building and site</u>. The durability and reliability of the building and site elements shall not be reduced by the H/C/HW systems to an extent that would significantly impair their intended function.
7.6.1	Criterion	<u>Exterior penetrations</u>. Openings in the exterior enclosure of the building through which connections, piping, ducting, and/or wiring are passed shall be made weather resistant and moisture proof.
	Evaluation	Review of drawings and specifications.
	Commentary	Particularly with collector supports, the penetration should either be accessible for maintenance or the assembly should be built tightly to the roof and flashed and caulked as necessary for watertightness. Reference [3] provides guidance for waterproofing penetration.
7.6.2	Criterion	<u>Interaction</u>. The interaction of building and site with solar systems and components shall be in accordance with applicable criteria of Chapter 5.
	Commentary	Applicable criteria include: 5.1.2, 5.1.3, 5.2.1, 5.3.3, 5.3.4, 5.3.5, and 5.4.1.
7.7	Requirement	<u>Maintainability of building and site</u>. The practical maintainability of the building or site shall not be significantly impaired by the H/C/HW systems.
7.7.1	Criterion	<u>Accessibility</u>. The location of the solar components shall not impair accessibility needed to maintain the building or site.
	Evaluation	Review of maintenance plans, site plans, and building drawings.
	Commentary	Roof maintenance may be difficult if collector installations are not designed for this need. The location of underground elements should be examined both to ensure that they can be maintained without trespassing on adjoining property and to ensure that they do not prevent digging, truck access, etc., necessary to maintain the facility or site.
7.7.2	Criterion	<u>Interaction</u>. The interaction of building and site with solar systems and components shall be in accordance with applicable criteria of Chapter 6.
	Commentary	Applicable criteria include: 6.1.1 thru 6.1.6, 6.1.9, 6.2.1, and 6.2.3.

References 7

1. ASHRAE Standard 90-75, Energy Conservation in New Building Design, 1975*.

2. Loftness, V., "Identifying Climatic Design Regions and Assessing Climatic Impact on Residential Building Design," AIA/RC, Technical Paper I, Winter 1977.

3. "A Manual of Roofing Practice," National Roofing Contractors Association, 1970 (71).

*American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc., 345 East 47th Street, New York, New York 10017.

APPENDIX 1

Table 1A-1 Direct Fired Water Heater Capacities. [1, 2]

FUEL		GAS	ELECT.	OIL	GAS	ELECT.	OIL	GAS	ELECT.	OIL	GAS	ELECT.	OIL
Number of Bedrooms		1			2			3			--		
1 to 1-1/2 Baths	Storage (gal)	20	20	30	30	30	30	30	40	30	--	--	--
	Input (Btuh or kw)	27K	2.5	70K	36K	3.5	70K	36K	4.5	70K	--	--	--
	Draw (gph)	43	30	89	60	44	89	60	58	89	--	--	--
	Recovery (gph)	23	10	59	30	14	59	30	18	59	--	--	--
Number of Bedrooms		2			3			4			5		
2 to 2-1/2 Baths	Storage (gal)	30	40	30	40	50	30	40	50	30	50	66	30
	Input (Btuh or kw)	36K	4.5	70K	36K	5.5	70K	38K	5.5	70K	47K	5.5	70K
	Draw (gph)	60	58	89	70	72	89	72	72	89	90	88	89
	Recovery (gph)	30	18	59	30	22	59	32	22	59	40	22	59
Number of Bedrooms		3			4			5			6		
3 to 3-1/2 Baths	Storage (gal)	40	50	30	50	66	30	50	66	30	50	80	40
	Input (Btuh or kw)	3bK	5.5	70K	38K	5.5	70K	47K	5.5	70K	50K	5.5	70K
	Draw (gph)	72	72	89	82	88	89	90	88	89	92	102	99
	Recovery (gph)	32	22	59	32	22	59	40	22	59	42	22	59

Note: Storage capacity, input and the recovery requirements indicated in the Table are typical and may vary with each individual manufacturer. Any combination of these requirements to produce the 1 hour draw stated will be satisfactory. Recovery is based on 100 F water temperature rise.

Example: For a 3-bedroom, 2 bath residence there are three choices as follows: A 40 gal storage/30 gph recovery gas heater; a 50 gal storage/22 gph recovery electric heater; or a 30 gal storage/59 gph recovery oil heater; or an equivalent combination which will produce at least a 70 gph total draw.

Table 1A-2 Indirect Fired Water Heater Capacities. [1, 2]

NUMBER OF BATHROOMS		1 to 1-1/2			2 to 2-1/2			3 to 3-1/2			
NUMBER OF BEDROOMS		2	3	4	3	4	5	3	4	5	6
TANK TYPE INDIRECT BOILER-CONNECTED WATER HEATER CAPACITIES (180 F BOILER WATER - INTERNAL OR EXTERNAL CONNECTION)	I-W-H rated gal in 3 hr 100 F degree rise	40	40	66	66	66	66	66	66	66	66
	Manufacturer rated gal. in 3 hr 100 F deg rise	49	49	75	75	75	75	75	75	75	75
	Tank capacity in gals.	66	66	66	66	66	82	66	82	82	82
TANKLESS TYPE INDIRECT BOILER- CONNECTED WATER HEATER CAPACITIES (200 F BOILER WATER - INTERNAL OR EXTERNAL CONNECTION)	I-W-H rated gpm. 100 F deg rise	2.75	2.75	3.25	3.25	3.25	3.75	3.25	3.75	3.75	3.75
	Manufacturer rated, draw in 5 min. 100 F deg rise	15	15	25	25	25	35	25	35	35	35

Note: Heater capacities and inputs are minimum allowable. Variations in tank size are permitted when recovery is based on 4 gph/kw @ 100 F rise for electrical, AGA recovery ratings for gas heaters, and IBR ratings for steam and hot water heaters.

Table 1A-3 Daily Hot Water usage (140°F) for Solar System Design

Category	One and two Family Units * and Apartments up to 20 Units					Apts. of [3] 20-200 Units	Apts. of [3] over 200 Units
No. of People	2	3	4	5	6	---	---
No. of Bedrooms	1	2	3	4	5	---	---
Hot Water/Unit (gal/day)	40	55	70	85	100	40	35

Table 1A-4 Monthly Temperature (t_m) in °F at Source for City Water in 14 Selected Cities [4]

City	Source	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1. Phoenix	Ri, Re, W	48	48	50	52	57	59	63	75	79	69	59	54
2. Miami	W	70	70	70	70	70	70	70	70	70	70	70	70
3. Los Angeles	Ri, W	50	50	54	63	68	73	74	76	75	69	61	55
4. Albuquerque	W	72	72	72	72	72	72	72	72	72	72	72	72
5. Las Vegas	W	73	73	73	73	73	73	73	73	73	73	73	73
6. Denver	Ri	39	40	43	49	55	60	63	64	63	56	45	37
7. Ft. Worth	L	56	49	57	70	75	81	79	83	81	72	56	46
8. Nashville	Ri	46	46	53	66	63	69	71	75	75	71	58	53
9. Washington, DC	Ri	42	42	52	56	63	67	67	78	79	68	55	46
10. Salt Lake City	W, C	35	37	38	41	43	47	53	52	48	43	38	37
11. Seattle	Ri	39	37	43	45	48	57	60	68	66	57	48	43
12. Boston	Re	32	36	39	52	58	71	74	67	60	56	48	45
13. Chicago	L	32	32	34	42	51	57	65	67	62	57	45	35
14. New York City	Re	36	35	36	39	47	54	58	60	61	57	48	45

Abbreviations: C-creek, L-lake, Re-reservoir, Ri-river, W-well.

* Assumes 20 gal. per person for first 2 people and 15 gal. per person for additional family members.

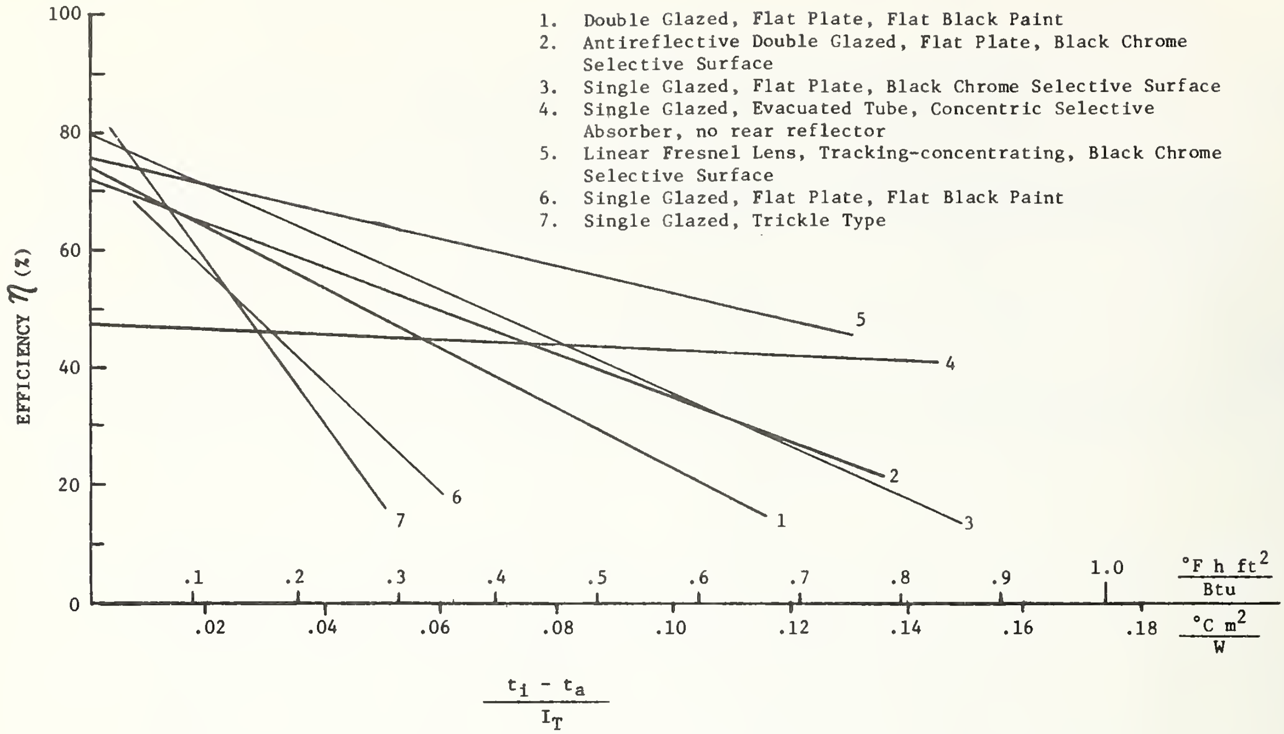

Figure 1A-1 Typical Thermal Efficiency Curves for Liquid Collectors Based on Collector Aperture Area

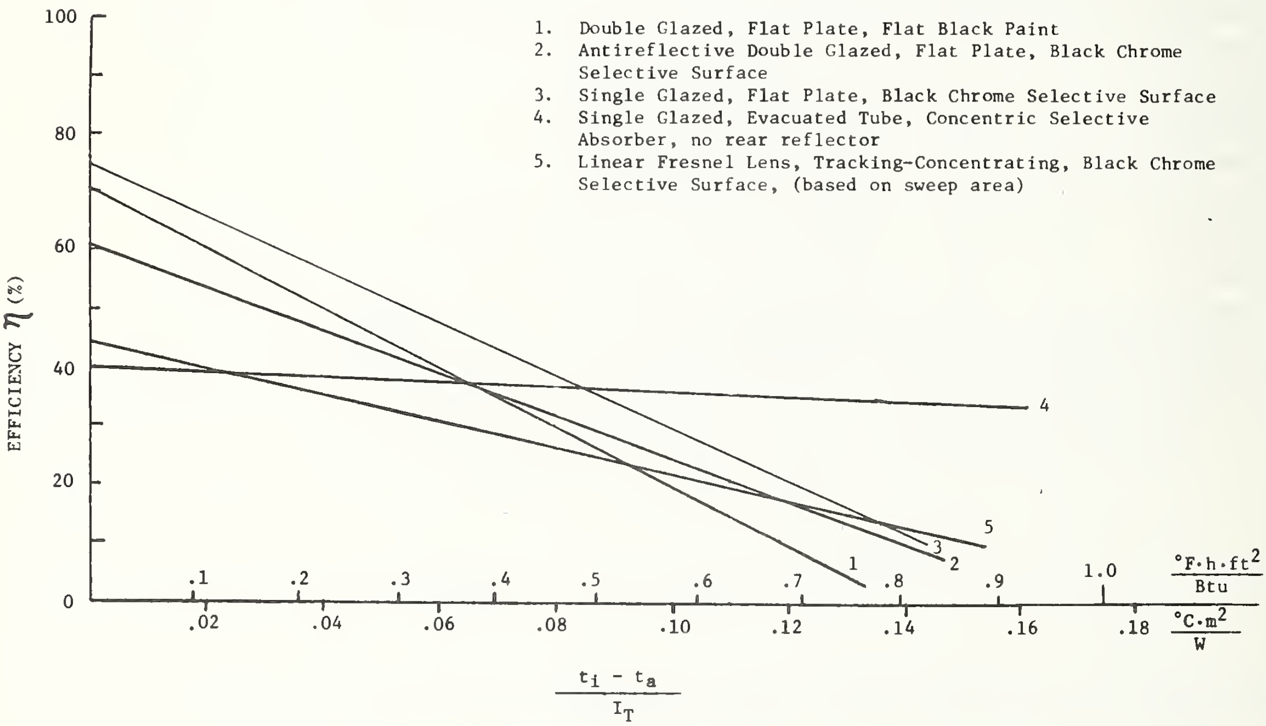

Figure 1A-2 Typical Thermal Efficiency Curves for Liquid Collectors Based on Collector Gross Frontal Area

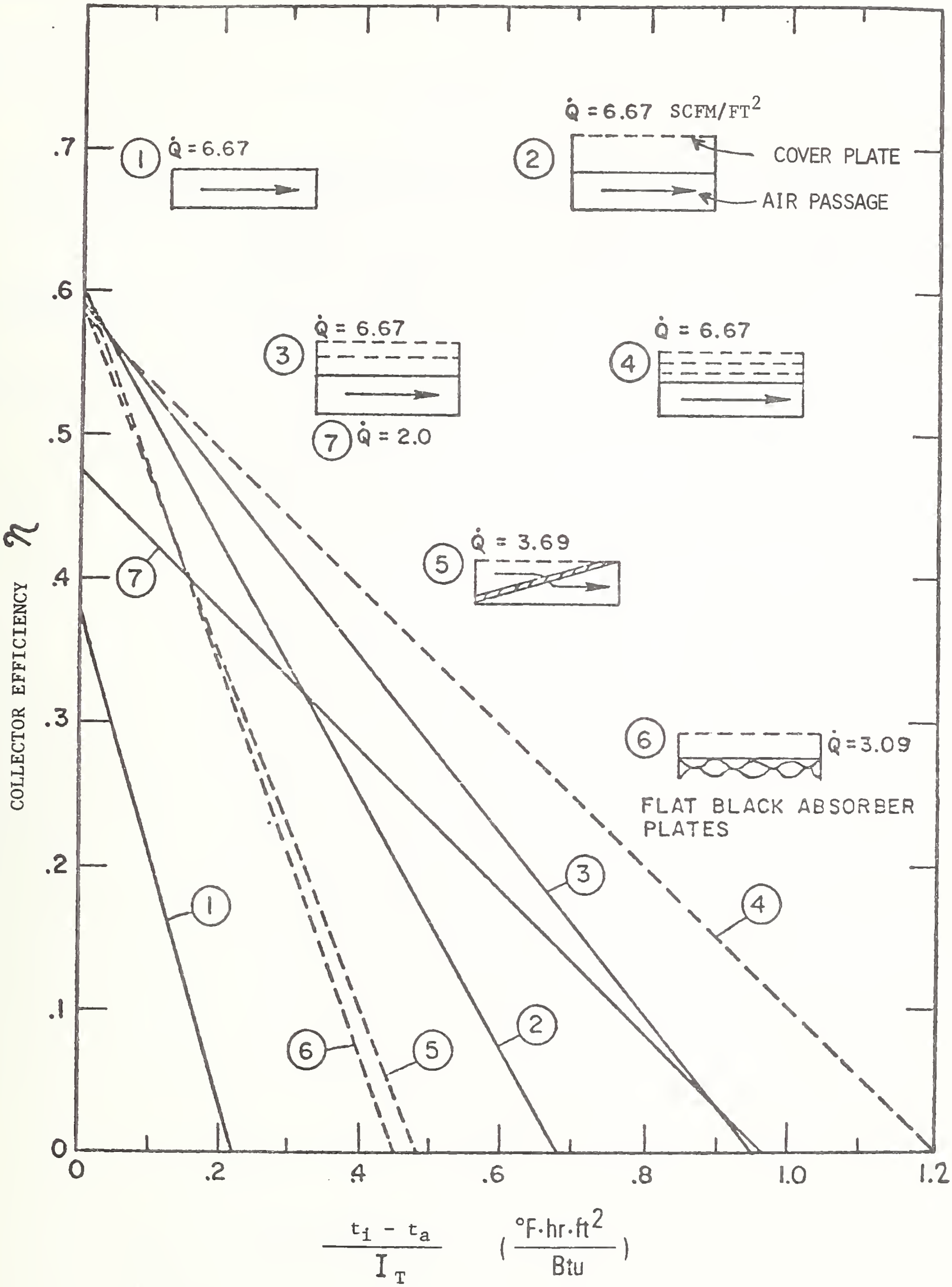

Figure 1A-3 Typical Thermal Efficiency Curves for Flat Plate Collectors Using Air as the Working Liquid, Based on Collector Gross Frontal Area [5]
(Q indicates flow rate in standard cubic feet per minute (scfm) per unit collector area)

References Appendix 1

1. HUD Minimum Property Standards, One and Two Family Dwellings, (No. 4900.0), U.S. Department of Housing and Urban Development, Washington, DC (1973, revised 1976).

2. HUD Minimum Property Standards, Multifamily Housing, (No. 4910.1), U.S. Department of Housing and Urban Development, Washington, DC (1973, revised 1976).

3. Werden, R. G. and Spielvogel, L. G., "Part II Sizing of Service Water Heating Equipment in Commercial and Institutional Buildings," ASHRAE Transactions, Volume 75, PII, 1969, p. i.v.1.1.

4. Data from Handbook of Air Conditioning System Design, pp. 5-41 through 5-46, McGraw-Hill Book Company, New York, NY, 1965.

5. Extended Abstracts, International Solar Energy Congress and Exposition (ISEC&E), Los Angeles, CA, July 1975.

(Note: This appendix has resulted from the reorganization of chapter 2 of "Interim Performance Criteria for Solar Heating and Combined Heating/Cooling Systems and Dwellings," Jan. 1975.)

APPENDIX 2

Section 1

Ice loads. The radial thickness of ice around the circumference of exposed wires, slender pipes, and similar members shall be based on the annual frequency of occurrence of glaze shown in Figure 2A-1 (see reference [12]) and shall be computed as follows:

Mean number of days with glaze	under 1	1-4	4-8	over 8
Thickness of ice (inches)	0	1/2	3/4	1.0

Commentary

The map of Figure 2A-1 with documented information of the accumulation of ice recorded for major ice storms [1] and ice loads considered in the design of steel transmission pole structures [2] have been utilized to relate thickness of ice to frequency of occurrence of such storms. This assumption is made in view of a lack of statistical data on accumulation of ice and should result in a generally conservative practice even though it is recognized that thickness of ice cannot be solely expressed in terms of rate of occurrence.

Section 2

Resistance of nonconventional elements. The factored resistance, R^*, of nonconventional elements is defined as follows:

$$R^* = \phi R_m$$

where:

R_m = mean, or best estimate, of the resistance expected under service conditions.

ϕ = resistance factor which depends on the coefficient of variation (c.o.v.) in resistance V_R, and the ductility, u, as follows:

Design Resistance Factor, ϕ

V_R	u: 2 or less	u: 5 or more
0.10	0.70	0.78
0.20	0.50	0.63
0.30	0.35	0.48

For intermediate values of V_R and u, ϕ may be obtained by linear interpolation.

R_m, V_R, and u shall be determined as indicated in the following paragraphs.

Where adequate existing test data on the various material properties comprising the system is available, evaluation of the mean resistance, R_m, shall be performed using engineering analysis. Where adequate test data is unavailable, system elements and subassemblies shall be evaluated in the laboratory using simulated static load levels consistent with the specified load combinations.

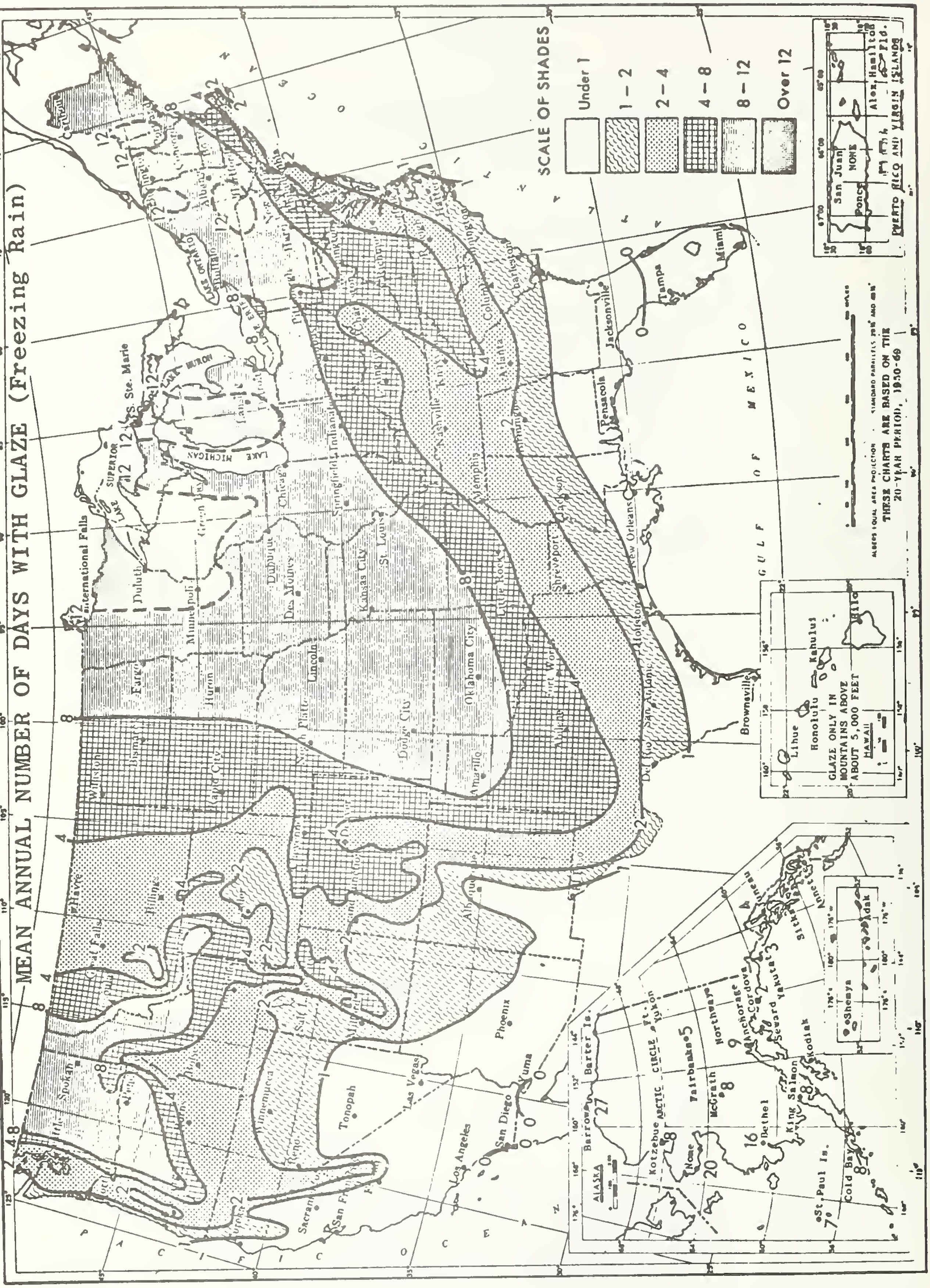

FIGURE 2A-1 Mean Annual Number of Days with Glaze (Freezing Rain) [1]

V_R shall be determined as:

$$V_R = [V_M^2 + V_F^2 + V_P^2]^{1/2} \geqq 0.10$$

Where

V_M is the c.o.v. in material strength relevant to the limit state of the component considered (i.e., yield or tensile strength, compression strength, etc.)

V_F is the c.o.v. attributable to fabrication, arising from dimensional variations in components and tolerances in the assembly of those components. V_F shall not be taken to be less than 0.05

V_P is the c.o.v. associated with the ability to predict the component capacity when all variables in the corresponding analytical model are precisely known. V_P shall not be taken to be less than 0.05

Coefficients of variation shall be determined in accordance with standard methods of statistical analysis using existing test data on materials comprising the system and laboratory tests conducted during the development and acceptance stages for innovative structural elements and subassemblies.

The ductility factor, u, is defined as the ratio of maximum obtainable deflection to yield deflection for structures with load-deformation relations (not stress-strain relations) that exhibit a relatively definite yield point. For structures that do not have such relations, the ductility factor, u, shall be computed from an "effective" function (Figure 2A-2) consisting of 2 straight lines. The first line is drawn through the origin and a point of the actual function at which the resistance is 60 percent of its maximum load value (P_u). The second line is a horizontal line ending at the ultimate deflection (d_u), which shall not exceed that where the resistance function falls below 95 percent of its maximum load value. The horizontal line is located so that the area under the 2 lines forming the effective function is equal to the area under the actual function up to the point of ultimate deflection. Effective yield deflection (d_{ye}) shall be taken as the deflection at the point of intersection of the 2 lines, which is at a resistance level termed "effective yield resistance." The ductility factor is based on the effective resistance function: $u = d_u / d_{ye}$.

Section 3

<u>Hail loads</u>. The design hail load shall be taken from the perpendicular impact of falling hail particles with a diameter (in inches) equal to 0.3d where d is the mean annual number of days with hail determined on the basis of the map shown in Figure 2A-3 and the velocity is the terminal velocity shown in Table 2A-1.

Commentary

The correlation of hail size with mean annual number of days with hail is based on studies on the probability of exceedance of a given particle size as a function of frequency of occurrence of hail, a twenty year recurrence interval reflecting the life expectancy of the system and observations of statistical data [3] indicating that a representative hail storm area is generally one order of magnitude smaller than the regions for which statistical information is compiled.

The impact from the vertical terminal velocity is used as a measure of the effect of hail falling with or without horizontal wind. It is possible that a larger impact could occur on surfaces sloped from 30° to 60° if the maximum particle diameter occurred simultaneously with a high horizontal wind velocity perpendicular to the surface. It may be overly conservative for particles over 1.5" impacting on near vertical surfaces. However, due to the lack of information on this phenomenon and the low probability of its occurrence, it is assumed that the terminal velocity gives the best measure of impact force consistent with the present state of the art.

Reference [4] describes the general NBS Hail Resistance Test, and Reference [5] describes a similar test directly applicable to flat plate solar collectors.

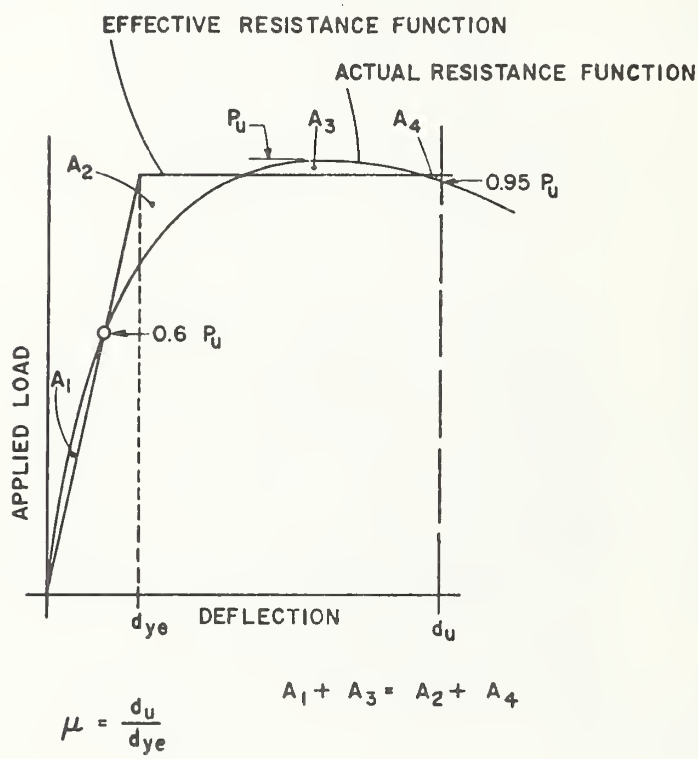

FIGURE 2A-2
Determination of the Ductility Factor

Diameter in	Weight gm	lb	Terminal Velocity ft/sec
1/2	0.98	0.002	51
3/4	3.30	0.007	62
1=	7.85	0.017	73
1 1/4	15.33	0.034	82
1 1/2	26.50	0.058	90
1 3/4	42.08	0.093	97
2	62.81	0.138	105
2 1/4	89.43	0.197	111
2 1/2	122.67	0.270	117
2 3/4	163.28	0.360	124
3	211.98	0.467	130

TABLE 2A-1
Values of Weight and Terminal Velocity, Computed for Smooth Ice Spheres

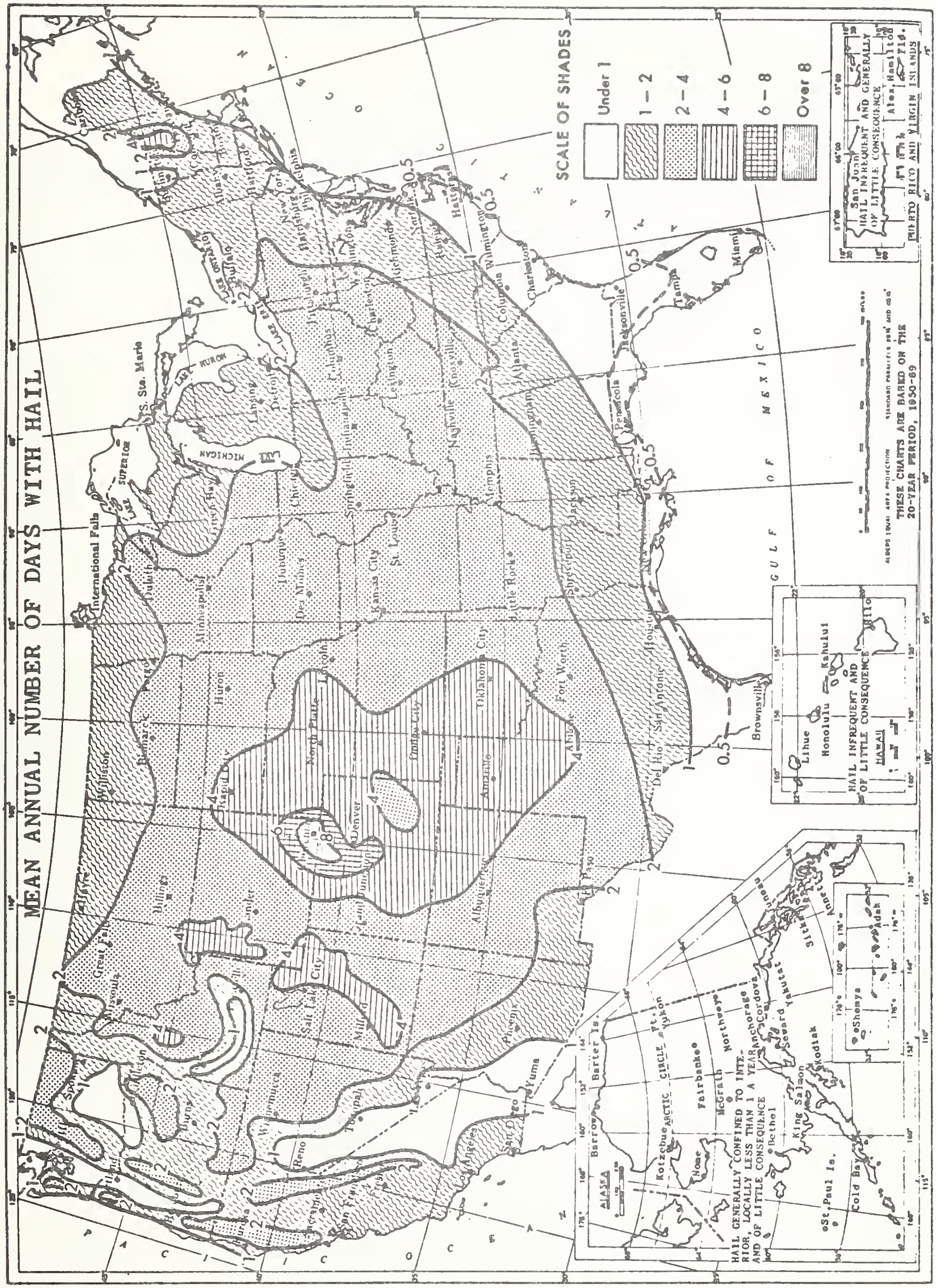

FIGURE 2A-3 Mean Annual Number of Days with Hail [1]

References Appendix 2

1. Baldwin, J. L., Climates of the United States, U.S. Department of Commerce, 1973.

2. "Design of Steel Transmission Pole Structures," Task Committee on Steel Transmission Poles of the Committee on Analysis and Design of Structures, Journal of the Structural Division, American Society of Civil Engineers, December 1974.

3. Mathey, R. G., Hail Resistance Tests of Aluminum Skin Honeycomb Panels for the Relocatable Lewis Building, Phase II, NBS Report 10193, 1970.

4. Greenfield, H., Hail Resistance of Roofing Products, Building Science Series 23, National Bureau of Standards, Washington, D.C. August 1969.

5. Provisional Flat Plate Solar Collector Testing Procedures, First Revision, NBSIR 78-1305A, National Bureau of Standards, Washington, D.C., June 1978.

(Note: This appendix has been significantly revised from "Interim Performance Criteria for Solar Heating and Combined Heating/Cooling Systems and Dwellings," January 1975.)

APPENDIX 3

Section 1 <u>Temperature Conditions</u>. Many of the criteria given in this chapter contain references to the maximum or minimum service temperatures in specifying the temperature at which testing should be performed. The <u>maximum service temperature</u> is the maximum temperature at which a system and its components are designed to operate, either with or without the flow of heat transfer fluid. The <u>minimum service temperature</u> refers to the minimum temperature at which a system and its components are designed to operate, with or without the flow of heat transfer fluid.

The minimum service temperature to which a component in the system will be exposed will generally occur when 1) no solar radiation is falling on the collector, 2) the heat transfer fluid is not flowing through the system, and 3) the ambient air temperature is at its lowest level. The no-flow condition mentioned above assumes the flow of the heat transfer fluid will be stopped when no useful energy can be removed from the collector to avoid pumping out heat energy. However, if the flow of fluid is not stopped at night, the minimum service temperature of some components may occur as nocturnal radiation and/or evaporative cooling takes place.

The maximum service temperature, to which the collector and components that are in intimate contact with it will be exposed, will generally occur when the collector is receiving its maximum level of solar radiation at maximum ambient temperature and the heat transfer fluid is not flowing through the collector (design maximum no-flow temperature). Other components, such as those in the storage subsystem, will generally reach their maximum temperature when the collector is receiving its maximum level of solar radiation at maximum ambient temperature and the heat transfer fluid is flowing through the system (design maximum flow temperature). A way of determining this temperature is by the limiting temperature of control devices or relief valves or through theoretical or test analysis of the system. The design maximum no-flow temperature that will occur at various locations in the collector can be calculated by use of an analytical model and appropriate environmental conditions. Typical examples of this type of information are shown in Figures 3A-1 to 3A-4.

Figures 3A-1 through 3A-4 are intended to provide assistance in establishing the maximum no-flow temperature of critical components for four "typical" collector designs. Cover plate and absorber plate temperatures are plotted as a function of ambient temperature for exposure to a solar radiation flux of 340 Btu/$ft^2 \cdot hr$ (1070 W/m^2). Data are shown for collectors with one and two cover plates with two cover glass materials (a typical window glass material and a more transparent glass material with a low iron oxide content) and with spectrally flat and selective black absorber coatings. The calculations were performed with a transient thermal analysis computer program using finite difference techniques.[1/] The calculations were based on the following assumptions: 1) a glass cover plate thickness of 1/8 in; 2) air space thickness of 3/8 in between both cover plates and between the absorber surface and the inner cover plate; 3) zero edge and back losses; 4) incident solar radiation is normal to the collector; and 5) the following properties of the glass cover plates:

1/ Ramsey, J. W., Borzoni, J. T. and Holland, T. H., "Development of Flat Plate Solar Collectors for the Heating and Cooling of Buildings," NASA CR-134804, June 1975.

Conventional Glass		Low Iron Oxide Glass	
absorptance	= 0.06	absorptance	= 0.02
extinction coeff.	= 0.70 per in	extinction coeff.	= 0.20 per in
index of refrac.	= 1.52	index of refrac.	= 1.52
thermal cond.	= 0.589 Btu/(ft·h·°F)	thermal cond.	= 0.589 Btu/(ft·h·°F)
transmittance	= 0.86	transmittance	= 0.90
emittance	= 0.86	emittance	= 0.86

It should be noted that the exposure conditions represent typical maximum conditions and that a higher solar radiation flux can be experienced under some atmospheric conditions or by the use of external reflectors. It is recommended that the temperature of critical components be experimentally established for particular collector designs whenever possible.

Section 2 Test Methodology: Criterion 5.1.1. Components or materials shall be tested using at least one of the following aging procedures and appropriate evaluation procedures.

The surfaces of components or materials shall be visually inspected before and after aging to ensure that no signs of excessive deterioration, such as dimensional changes, cracking, chalking, or other visually detectable changes which could significantly affect the performance of the components in the system, are present. In addition, other evaluation procedures shall be used, as necessary, to evaluate performance.

Aging Procedure 1

ASTM reference methods for Aging Procedure 1 include G26-70 Operating Light and Water Exposure Apparatus (Xenon-Arc Type) for Exposure of Non-Metallic Materials, and D2565-75, Operating Xenon Arc-Type (Water-Cooled) Light and Water Exposure Apparatus for Exposure of Plastics.

Expose components or materials to simulated solar radiation (such as xenon arc radiation) for a period of 2,000 equivalent sun hours. The exterior surfaces of components which are exposed to rainfall in service shall be subjected to a water spray for a period of 5 minutes during each 60 minutes of the light exposure. For components not exposed to rainfall under normal operating conditions, the water spray shall not be included in the procedure.

Aging Procedure 2

Expose components or materials to concentrated natural solar radiation using machines such as those referenced in ANSI Z97.1-1975, paragraph 4.3.2, for a period of 2,000 equivalent sun hours. The exterior surfaces of components which are exposed to rainfall in service shall be subject to a water spray for a period of 8 minutes during each 60 minutes of sunlight exposure. For components not exposed to rainfall under normal operating conditions, the water spray shall not be included in the procedure.

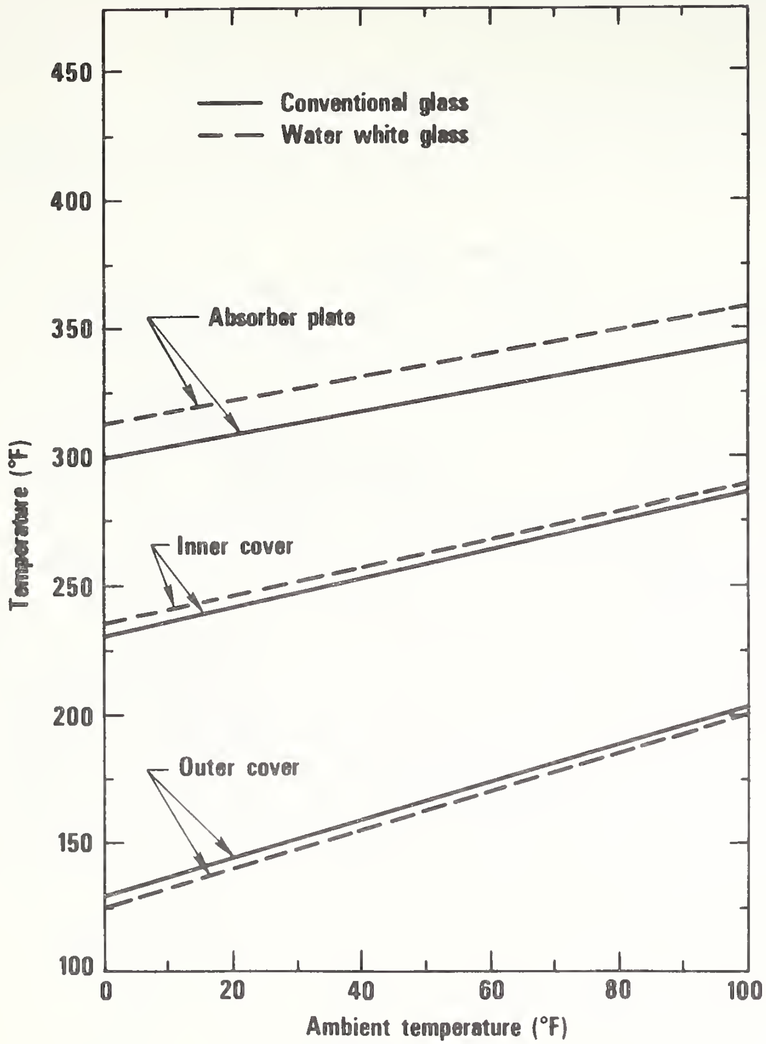

Figure 3A-1 Maximum No Flow Temperatures at Various Locations in a Collector with a Flat Black Absorber (Absorptivity = 0.9, Emissivity = 0.9) and Two Glass Cover Plates (I = 340 Btu/Hr.ft^2, no wind)

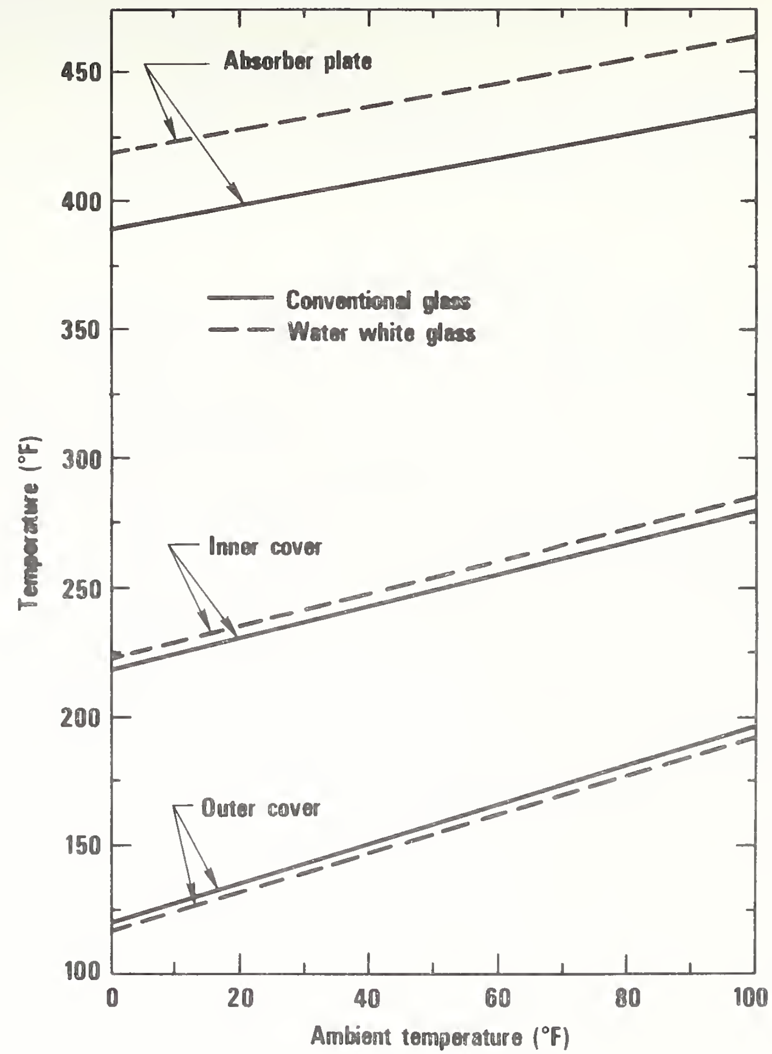

Figure 3A-2 Maximum No Flow-Temperatures at Various Locations in a Collector with a Selective Absorber (Absorptivity = 0.9, Emissivity = 0.1) and Two Glass Cover Plates (I = 340 Btu/Hr.ft^2, no wind)

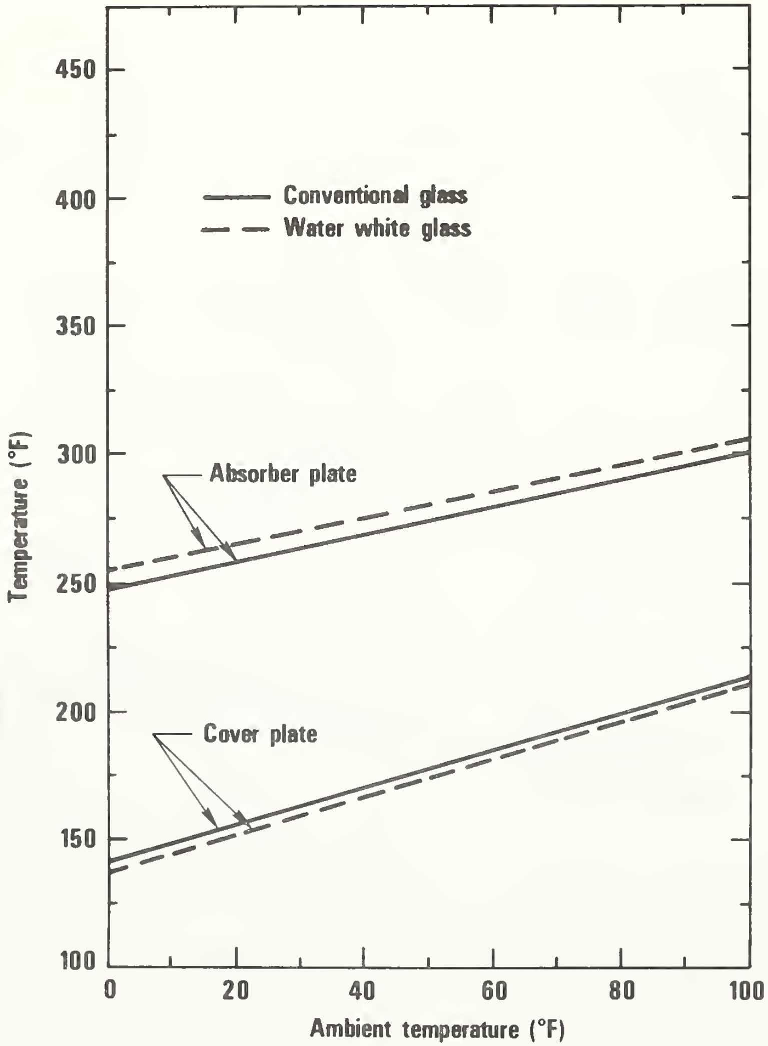

Figure 3A-3 Maximum No Flow-Temperatures at Various Locations in a Collector with Flat Black Absorber (Absorptivity = 0.9, Emissivity = 0.9) and One Glass Cover Plate (I = 340 Btu/Hr.ft^2, no wind)

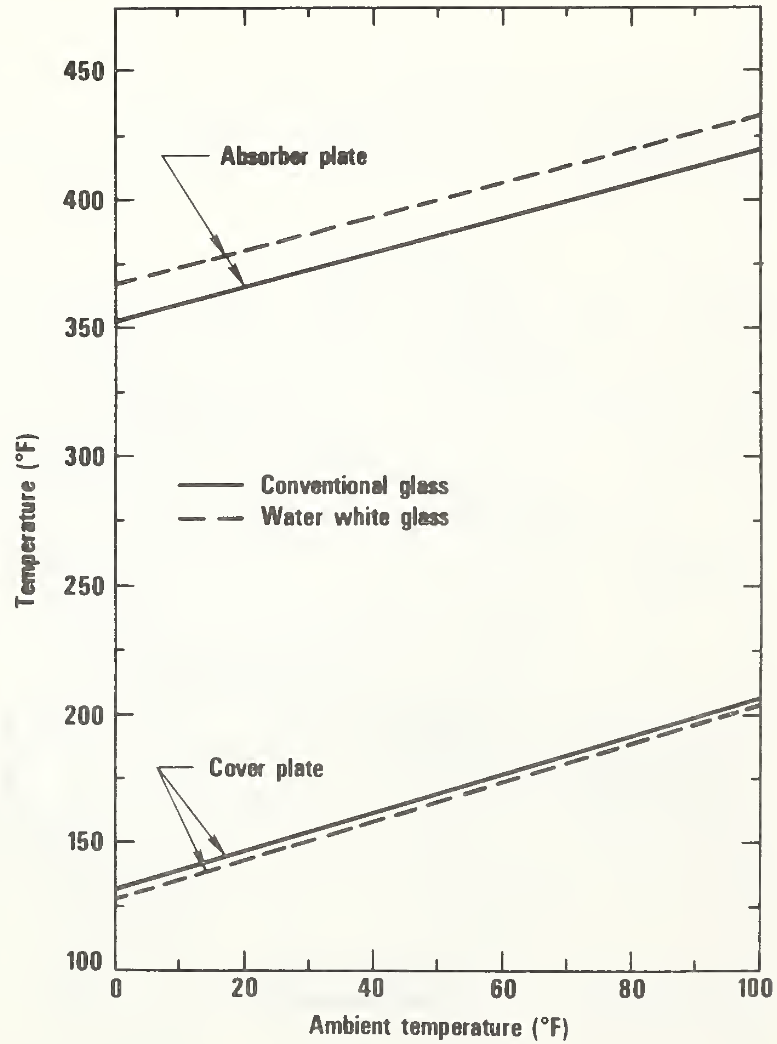

Figure 3A-4 Maximum No Flow-Temperatures at Various Locations in a Collector with a Selective Absorber (Absorptivity = 0.9, Emissivity = 0.1) and One Glass Cover Plate (I = 340 Btu/Hr.ft^2, no wind)

Aging Procedure 3

ASTM reference methods for Aging Procedure 3 include:

D1006-73	Conducting Exterior Exposure Tests of Paints on Wood
D1014-66 (1973)	Conducting Exterior Exposure Tests of Paints on Steel
D1435-75	Outdoor Weathering of Plastics
D1828-70	Atmospheric Exposure of Adhesive Bonded Joints and Structures
G7-77	Atmospheric Environmental Exposure Testing of Non-Metallic Materials
G11-72	Effects of Outdoor Weathering on Pipeline Coatings
G24-73	Conducting Natural Light Exposure Under Glass

Expose components and materials to solar radiation outdoors for twelve months. The average daily flux of the solar radiation, as obtained by averaging the daily fluxes over the twelve month period of outdoor exposure, shall be at least 1300 Btu/ft^2 (350 Langleys).

Evaluation

Evaluation procedures shall be selected to measure the effect of the aging procedures on important properties of the components or materials.

Absorber coatings and polymeric cover plate materials shall be evaluated before and after aging for optical properties, i.e. absorptance, emittance and transmittance, as appropriate, using the following ASTM methods:

E408-71	Total Normal Emittance of Surfaces Using Inspection Meter Techniques
E424-71 (Method A)	Solar Energy Transmittance and Reflectance of Sheet Materials

Other evaluation procedures shall be used, as appropriate. The following ASTM procedures are illustrative of the types of procedures that may be used:

Physical Deterioration

D659-74	Evaluating Degree of Resistance of Chalking of Exterior Paints
D660-44 (1970)	Evaluating Degree of Resistance of Checking of Exterior Paints
D661-44 (1975)	Evaluating Degree of Resistance of Cracking of Exterior Paints
D714-56 (1974)	Evaluating Degree of Blistering of Paints

Tensile Strength

C297-61 (1970)	Tension Test of Flat Sandwich Construction in Flatwise Plane
D638-76	Tensile Properties of Plastics
D897-72	Tensile Properties of Adhesive Bonds

Flexure Strength

C158-72	Flexure Testing of Glass (Determination of Modulus of Rupture)
C393-62 (1970)	Flexure Test of Flat Sandwich Constructions
D790-71	Flexural Properties of Plastics and Electrical Insulating Materials

Evaluations should be performed on both aged and unaged specimens to establish a basis of comparison.

Commentary

The tests are intended to permit estimations to be made of the effect of solar radiation in degrading collector components and in reducing the collector efficiency. The 2,000 equivalent sun hours test time is considered to be equivalent to approximately 12 months of actual solar exposure with an average exposure time of 6 hours per day. The fact that the intensity of solar radiation varies with time of the day and time of the year should be considered in establishing the length of the exposure.

Section 3

Test Methodology: Criterion 5.1.4. Testing of non-ferrous metals shall be performed for a period of 500 hours at the maximum service temperature. During the duration of the test, coupon specimens shall be partially immersed in aqueous solutions having a pH equivalent to that found in soil specimens taken from the sites where the systems are intended to be used. ASTM G31-72 may be useful in performing immersion tests. Testing of ferrous metals shall be by either the four probe technique or the soil box technique. Both techniques measure soil resistivity. If the probe technique is used, probe spacing shall be adjusted to measure the soil resistivity at the depth at which the ferrous member is to be buried. Similarly, soil box samples shall be obtained from that depth. These tests shall not be carried out when the soil is frozen but shall be performed when the soil contains its maximum moisture content.

The resistivity values below give a rough indication of the relationship between soil corrosivity and resistivity.

Resistivity, ohm-cm	Soil Corrosivity
Below 500	very corrosive
500 - 1,000	very corrosive
1,000 - 2,000	moderately corrosive
2,000 - 10,000	mildly corrosive
above 10,000	progressively less corrosive

The resistivity of the soil shall be 5,000 ohm-cm or greater if unprotected ferrous metals are to be buried in the soil. Wood to be buried in soil shall be resistant to natural decay when evaluated by ASTM D2017-71.

Section 4

Test Methodology: Criterion 5.1.5. This section contains test methods to determine the resistance of components to airborne pollutants. Following the test, specimens shall exhibit no signs of deterioration that would significantly impair their performance.

A. Resistance to Ozone

Coupon specimens of components shall be exposed for 21 days to an ozone atmosphere of 50 ± 5 pphm/volume in a test chamber at 23 ± 2°C (73.4 ± 3.6°F). After exposure, the surfaces of the specimens shall be visually examined for signs of deterioration such as cracking, blistering, or dimensional changes using a microscope with an eye-piece micrometer at 20X magnification. An ozone test chamber is described in ASTM D1149-64 (1970), "Accelerated Ozone Cracking of Vulcanized Rubber." Specimens should be stressed to simulate service conditions

The extent of change of the specimens as a result of the exposure shall be determined by comparing the exposed specimens to control specimens or by comparing the characteristics of the same specimens before and after exposure.

B. Resistance to Salt Spray

Coupon specimens of components shall be evaluated in accordance with ASTM Standard Method B117-73. After exposure for 21 days the specimens shall be visually examined for signs of deterioration such as cracking, crazing, blistering, or pitting. The extent of the change as a result of the exposure shall be determined by comparing the exposed specimens to control specimens or by comparing the characteristics of the same specimens before and after exposure.

C. Resistance of SO_2 and NO_x

Coupon specimens of components are to be supported vertically in a closed chamber having openings for gas inlet and outlet and maintained at a temperature of 23 ± 2°C (73.4 ± 3.6°F) for a period of 21 days. An amount of (SO_2 or NO_x) equivalent to 1 percent of the volume of the test chamber shall be introduced into the chamber each working day. A small amount of water is to be maintained at the bottom of the chamber.

Section 5

Test Methodology: Criterion 5.2.1. Complete components or coupon specimens shall be subjected to heat aging for a period of 21 days at the maximum service temperature. Components and materials stressed in normal use should be stressed during the exposure. They shall be evaluated using evaluative procedures described in Section 2 of this Appendix.

When evaluated after exposure to the maximum service temperature, there shall be no significant signs of cracking, crazing, or blistering and there shall be no significant change in optical properties of absorber and cover plate materials. Also, the specimens shall exhibit no significant loss of strength as a result of the aging.

Section 6 Test Methodology: Criterion 5.2.2. All fluids shall be subjected to the two tests below:

Test 1 - Expose the fluids to their maximum service temperature for a period of 21 days. The fluids shall contain turnings of the metal to be used in service in quantities of 10 g of metal turnings to 100 cc of fluid. Fluid aeration shall be included in fluids to be used in "open" systems. Fluid aeration need not be included for "closed" system usage. The test must be repeated for all metal materials that are present in the system.

Test 2 - Expose the fluids to their minimum service temperature for a period of 24 hours.

At the completion of test 1, inspect the fluids visually for signs of undesired changes such as excessive precipitation or boiling. Also, before and after test 1, measure the pH and the viscosity of the fluid and evaluate the infrared spectrum of the fluid to ensure fluid stability. After the tests, the fluids shall not exhibit changes that would significantly impair their ability to function. At the completion of test 2, examine the fluid for an indication of freezing.

Section 7 Test Methodology: Criterion 5.3.1. Test the components for 100 hours at the maximum service temperature using ASTM D471-75. Components shall be stressed to simulate service conditions.

At the end of each test, visually inspect the components for signs of cracking, swelling. or other dimensional changes or loss of adhesion to adjoining components.

Section 8 Test Methodology: Criterion 5.3.2. Coupon specimens, or entire components, shall be immersed in the heat transfer fluid for a period of 42 days. During the test, the temperature of the fluid surrounding the specimens shall be cycled repetitively as follows: 20 hours at the maximum service temperature followed by cooling to minimum service temperature and reheating to the maximum service temperature over a four hour period. Appropriate modifications including flow rate and degree of fluid aeration shall be included in the test. Protective coatings shall form a part of the test specimen if they are used in the actual system. Testing shall be followed by visual inspection. Standard TM-01-71, Autoclave Corrosion Testing of Metal in High Temperature Water, of the National Association of Corrosion Engineers for materials used in pressurized systems or ASTM D2570-73, Simulated Service Corrosion Testing of Engine Coolants for materials used in systems at atmospheric pressure, may be used in the evaluation of metals.

Following the test, the test specimens shall not show signs of pitting, crevices, erosion or exhibit other signs of general corrosive deterioration with the exception of discoloration.

Section 9 Test Methodology: Criterion 5.3.3

Adjoining Dissimilar Materials Used in Contact with the Transfer Fluid

Test specimens consisting of dissimilar materials in direct contact with one another shall be immersed in the heat transfer fluid for a period of 42 days at the maximum service temperature according to ASTM D1384-70 (1975). During the test, the heat transfer fluid shall be circulated to simulate flow rate and degree of fluid aeration. This shall be followed by visual observation. Protective coatings shall be used when they form a part of the component.

Adjoining Dissimilar Materials Not Used in Contact with the Transfer Fluid

Test specimens consisting of dissimilar materials in direct contact with one another shall be subject to the test as described in Section 4, resistance to SO_2 and NO_x.

Section 10 Test Methodology: Criterion 5.3.4. Expose components containing leachable substances and components that may be affected by the leachable substances in water or steam for a period of 500 hours at the maximum service temperature. At the end of the exposure, visually inspect the component that may have been affected by the leachable substance for signs of deterioration such as pitting, cracking, or dimensional changes.

Section 11 Test Methodology: Criterion 5.3.5. The evaluation shall consist of two stages. In the first stage, components shall be heated to their maximum service temperature for two hours and the composition of the decomposition products, if any, shall be determined. Analysis for organic materials could be by infrared spectroscopy or chromatography. Standard wet chemical techniques could be used for inorganic substances.

The second stage of the evaluation shall be performed if the amount and types of decomposition products are significant. The second stage shall consist of subjecting components, that would be exposed to the decomposition products in actual service, to the decomposition products in a test chamber for 100 hours at the maximum service temperature of the components being tested. The concentration of the decomposition products shall be the maximum concentration expected in actual service. During the exposure, moisture shall be added to the test chamber to maintain relative humidity of 90% or greater.

After the exposure, test specimens shall be visually examined for signs of degradation such as cracking, corrosion, and swelling or other dimensional changes.

Section 12 Materials Tables

TABLE 3A-2 Usually Acceptable and Unacceptable Use Conditions for Metals in Direct Contact with Heat Transfer Liquids in Open Systems

Usually Unacceptable Use Conditions	Usually Acceptable Use Conditions 1/
Aluminum	
1. When in direct contact with untreated tap water with pH <5 or >9.	1. When in direct contact with distilled or deionized water which contains appropriate inhibitors and does not contact copper or iron.
2. When in direct contact with aqueous liquid containing less electro positive metal ions, such as copper or iron or halide ions.	2. When in direct contact with distilled or deionized water which contains appropriate inhibitors and a means of removing heavy metal ions obtained from contact with copper or iron.
3. When specific data regarding the behavior of a particular alloy are not available, the velocity of aqueous liquid shall not exceed 4 ft/sec.	3. When in direct contact with stable anhydrous organic liquids.
4. When in direct contact with a liquid which is in contact with corrosive fluxes.	
Copper	
1. When in direct contact with aqueous liquid containing high concentrations of chlorides, sulfates or liquid which contains hydrogen sulfide.	1. When in direct contact with distilled, deionized or low chloride, low sulfate and low sulfide tap water.
2. When in direct contact with chemicals that can form copper complexes such as ammonium compounds.	2. When in direct contact with stable anhydrous organic liquids.
3. When in direct contact with an aqueous liquid having a velocity greater than 4 ft/sec. 2/	
4. When in direct contact with a liquid which is in contact with corrosive fluxes.	
5. When in contact with an aqueous liquid with a pH lower than 5.	
6. When the copper surface is initially locally covered with a copper oxide film or a carbonaceous film.	
7. When operating under conditions conducive to water line corrosion.	
Steel	
1. When in direct contact with untreated tap, distilled or deionized water with pH <8 or >12.	1. When in direct contact with distilled, deionized or low salt content water which contains appropriate corrosion inhibitors.
2. When in direct contact with a liquid which is in contact with corrosive fluxes.	2. When in direct contact with stable anhydrous organic liquids.
3. When in direct contact with an aqueous liquid having a velocity greater than 6 ft/sec. 2/	3. When adequate cathodic protection of the steel is used (practical only for storage tanks).
4. When operating under conditions conducive to water line corrosion.	

TABLE 3A-2 (Contd.)

Usually Unacceptable Use Conditions	Usually Acceptable Use Conditions [1/]
Stainless Steel	
1. When the grade of stainless steel selected is not corrosion resistant in the anticipated heat transfer liquid.	1. When the grade of stainless steel selected is resistant to pitting, crevice corrosion, intergranular attack and stress corrosion cracking in the anticipated use conditions.
2. When in direct contact with a liquid which is in contact with corrosive fluxes.	2. When in direct contact with stable anhydrous organic liquids.
Galvanized Steel	
1. When in direct contact with aqueous liquid containing copper ions.	1. When adequate cathodic protection of the galvanized parts is used (practical only for storage tanks).
2. When in direct contact with aqueous liquid with pH <8 or >12.	2. When in contact with stable anhydrous organic liquids.
3. When in direct contact with aqueous liquid with a temperature >55°C.	

Brass and Other Copper Alloys

Binary copper-zinc brass alloys (CDA 2XXX series) exhibit generally the same behavior as copper when exposed to the same conditions. However, the brass selected should resist dezincification in the operating conditions anticipated. At zinc contents of 15% and greater, these alloys become increasingly susceptible to stress corrosion. Selection of brass with a zinc content below 15% is advised. There are a variety of other copper alloys available, notably copper-nickel alloys, which have been developed to provide improved corrosion performance in aqueous environments.

1/ The use of suitable antifreeze agents and buffers is acceptable provided they do not promote corrosion of the metallic liquid containment system. The use of suitable corrosion inhibitors for specific metals is acceptable provided they do not promote corrosion of other metals present in the system. If thermal or chemical degradation of these compounds occurs, the degradation products should not promote corrosion.

2/ The flow rates at which erosion/corrosion becomes significant will vary with the conditions of operation. Accordingly, the value listed is approximate.

TABLE 3A-3 Usually Acceptable and Unacceptable Use Conditions for Metals in Direct Contact with Heat Transfer Liquids in Closed Systems.

Usually Unacceptable Use Conditions	Usually Acceptable Use Conditions [1/]
Aluminum	
1. When in direct contact with untreated tap water with pH <5 or >9.	1. When in direct contact with distilled or deionized water which contains appropriate corrosion inhibitors.
2. When in direct contact with liquid containing copper, iron or halide ions.	2. When in direct contact with stable anhydrous organic liquids.
3. When specified data regarding the behavior of a particular alloy are not available, the velocity of aqueous liquid shall not exceed 4 ft/sec.	

TABLE 3A-3 (Contd.)

Usually Unacceptable Use Conditions	Usually Acceptable Use Conditions [1]
Copper	
1. When in direct contact with an aqueous liquid having a velocity greater than 4 ft/sec.[2]	1. When in direct contact with untreated tap, distilled or deionized water.
2. When in contact with chemicals that can form copper complexes such as ammonium compounds.	2. When in direct contact with stable anhydrous organic liquids.
	3. When in direct contact with aqueous liquids which do not form complexes with copper.
Steel	
1. When in direct contact with liquid having a velocity greater than 6 ft/sec.[2]	1. When in direct contact with untreated tap, distilled or deionized water with pH >8 or <12.
2. When in direct contact with untreated tap, distilled or deionized water with pH <8 or >12.	2. When in direct contact with stable anhydrous organic liquids.
	3. When in direct contact with aqueous liquids of pH >8 or <12.
Stainless Steel	
1. When the grade of stainless steel selected is not corrosion resistant in the anticipated heat transfer liquid.	1. When the grade of stainless steel selected is resistant to pitting, crevice corrosion, intergranular attack and stress corrosion cracking in the anticipated use conditions.
2. When in direct contact with a liquid which is in contact with corrosive fluxes.	2. When in direct contact with stable anhydrous organic liquids.
Galvanized Steel	
1. When in direct contact with water with pH <8 or >12.	1. When in contact with water of pH >8 but <12.
2. When in direct contact with an aqueous liquid with a temperature >55°C.	

Brass and Other Copper Alloys

Binary copper-zinc brass alloys (CDA 2XXX series) exhibit generally the same behavior as copper when exposed to the same conditions. However, the brass selected shall resist dezincification in the operating conditions anticipated. At zinc contents of 15% and greater, these alloys become increasingly susceptible to stress corrosion. Selection of brass with a zinc content below 15% is advised. There are a variety of other copper alloys available, notably copper-nickel alloys, which have been developed to provide improved corrosion performance in aqueous environments.

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[1] The use of suitable antifreeze agents and buffers is acceptable provided they do not promote corrosion of the metallic liquid containment system. The use of suitable corrosion inhibitors for specific metals is acceptable provided they do not promote corrosion of other metals present in the system. If thermal or chemical degradation of these compounds occurs, the degradation products should not promote corrosion.

[2] The flow rates at which erosion/corrosion becomes significant will vary with the conditions of operation. Accordingly, the value listed is approximate.

TABLE 3A-4 Properties of Typical Cover Plate Materials[1/]

Material / Property	Poly(vinyl fluoride)	Poly(ethylene terephthalate)	Polycarbonate	Fiberglass Reinforced Plastics	Poly(methyl methacrylate)	Perfluoro copolymer (ethylene propylene)	Clear Lime Glass (Float)	Sheet Lime Glass	Water White Glass
% Solar Transmittance (for thickness listed below)	92-94	85	81	77-90	89	96	83-85	84-87	91
Maximum Operating Temperature (°F)	227	220 -350	230-270	200	180-190	410	400	400	400
Tensile Strength (psi)	13000	24000	9500	15000-17000	10500	2700-3100	4000 annealed 10000 tempered	4000 annealed 10000 tempered	4000 annealed 10000 tempered
Thermal Expansion Coefficient (in/in/°F x 10^{-6})	28	15	37.5	18-22	41.0	8.3-10.5	4.8	5.0	4.7-8.6
Elastic Modulus (psi x 10^6)	.26	.55	.345	1.1	.45	.5	10.5	10.5	10.5
Thickness (in)	.004	.001	.125	.040	.125	.002	.125	.125	.125
Weight (lb/ft^2) For above thickness	.028	.007	.77	.30	.75	.002	1.63	1.63	1.63
Refractive Index	1.46	1.64	1.59	1.52-1.54	1.49	1.34	1.51	1.52	1.50

1/ These values were obtained from the following references:

Grimmer, D. P., Moore, S. W., "Practical Aspects of Solar Heating: A Review of Materials Used in Solar Heating Applications." LA-UR-75-1952, paper presented at SAMPE Meeting, October 14-16, 1975.

Kobayashi, T., Sargent, L., "A Survey of Breakage-Resistant Materials for Flat-Plate Solar Collector Covers," paper presented at U.S. Section-ISES Meeting, Ft. Collins, Colorado, August 20-23, 1974.

Scoville, A. E., "An Alternate Cover Material for Solar Collectors,' paper presented at ISES Congress and Exposition, Los Angeles, California, July, 1975.

Clarkson, C. W., Herbert, J. S., "Transparent Glazing Media for Solar Energy Collectors," paper presented at U.S. Section-ISES Meeting, Ft. Collins, Colorado, August 21-23, 1974.

Modern Plastics Encyclopedia, 1975-1976, McGraw-Hill Publishing Company.

Toenjes, R. B., "Integrated Solar Energy Collector Final Summary Report," LA-6143-MS, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, November, 1975.

APPENDIX 3 Cont.

TABLE 3A-5 Characteristics of Absorptive Coatings[1/]

Property / Material	Absorptance[2/] α	Emittance ε	α/ε	Breakdown Temperature °F (°C)	Comments
Anodic Aluminum	.94-.96	.3-.8			May Be Influenced By Moisture
Black Chrome	.87-.93	.1	∿9		
Alkyd Enamel	.90	.9	1		Durability Limited at High Temperatures
Black Acrylic Paint	.92-.97	.84-.90	∿1		
Black Inorganic Paint	.89-.96	.86-.93	∿1		
Black Silicone Paint	.86-.96	.83-.89	∿1		Silicone Binder
PbS/Silicone Paint	.94	.4	2.5	662 (350)	Has a High Emittance for Thicknesses >10μm
Flat Black Paint	.95-.98	.89-.97	∿1		
Ceramic Enamel	.93	.84	1.1		Stable at High Temperatures
Black Zinc	.90	.1	9		
Copper Oxide over Aluminum	.93	.11	8.5	392 (200)	
Black Copper over Copper	.85-.90	.08-.12	7-11	842 (450)	Patinates with Moisture
Black Chrome over Nickel	.92-.96	.07-.12	8-13	842 (450)	Stable at High Temperatures
Black Nickel over Nickel	.93	.06	15	842 (450)	May be Influenced by Moisture at Elevated Temperatures
Ni-Zn-S over Nickel	.96	.07	14	536 (280)	
Black Iron over Steel	.90	.10	9		

[1/] These valves were obtained from the following references:

G. E. McDonald, "Survey of Coatings for Solar Collectors", NASA TMX-71730, paper presented at Workshop on Solar Collectors for Heating and Cooling of Buildings, November 21-23, 1974, New York City.

G. E. McDonald, "Variation of Solar-Selective Properties of Black Chrome with Plating Time", NASA TMX-71731, May 1975.

S. W. Moore, J. D. Balcomb, J. C. Hedstrom, "Design and Testing of a Structurally Integrated Steel Solar Collector Unit Based on Expanded Flat Metal Plates", LA-UR-74-1093, paper presented at U. S. Section-ISES Meeting, Ft. Collins, Colorado, August 19-23, 1974.

D. P. Grimmer, S. W. Moore, "Practical Aspects of Solar Heating: A Review of Materials Use in Solar Heating Applications", paper presented at SAMPE Meeting, October 14-16, 1975, Hilton Inn.

R. B. Toenjes, "Integrated Solar Energy Collector Final Summary Report", LA-6143-MS, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, November 1975.

G. L. Merrill, "Solar Heating Proof-of-Concept Experiment for a Public School Building", Honeywell Inc., Minneapolis, Minnesota National Science Foundation Contract No. C-870.

D. L. Kirkpatrick, "Solar Collector Design and Performance Experience", for the Grover Cleveland School, Boston, Massachusetts, paper presented at Workshop on Solar Collectors for Heating and Cooling of Buildings, November 21-23, 1974, New York City.

[2/] Dependent on thickness and vehicle to binder ratio.

TABLE 3A-6 Properties of Typical Absorber Substrate Materials[1/]

Material / Property	Aluminum	Copper	Mild Carbon Steel	Stainless Steel
Elastic Modulus, Tension psi x 10^6	10	19	29	28
Density lbs/cu.in.	0.098	0.323	0.283	0.280
Expansion Coefficient (68-212°F) in/in/°F x 10^{-6}	13.1	9.83	8.4	5.5
Thermal Conductivity (77-212°F) Btu/hr·ft^2·°F/ft	128	218	27	12
Specific Heat (212 °F) Btu/lb·°F	0.22	0.09	0.11	0.11

1/ Typical values: standard specifications or manufacturer's literature should be consulted for specific types or alloys.

TABLE 3A-7 Thermal Storage Unit Containers 1/

Container / Material	Usage: Above Ground	Usage: Below Ground	Transfer Media: Air	Transfer Media: Liquid	Pressure Conditions: High	Pressure Conditions: Low 2/	Recommended 3/ Container Standard Compliance	Protective Coating: Ext.	Protective Coating: Int.	Recommended Coating Standard Compliance
Aluminum	X		X	X	X	X	ANSI B96.1 1973	-	-	-
Concrete	X	X	X	X	X	X	IAPMO PSI (1966)	X	X	Ext. MPS 609-7.3 Int. TTP-95A(3) 27 May 66
Earth		X	X			X	Vapor Barrier Materials as per ASTM E154.68	Vapor Barrier Covering of Solids Required		MPS 507.2.2
Plastics	X	X	X	X		X	MIL-T-52777 4/ 21 Feb 1974	-	-	-
Steel	X	X	X	X	X	X	AWWA D-100 (1967)	X	X	Ext. MPS 609-7.4 5/ Ext. & Int. AWWA D102 (1964)
Wood	X		X	X		X	NWTI S-75 6/	-	-	-

1/ Thermal Storage Unit - any container, space, or device which has the capacity to store transfer media (liquid or solid) containing thermal energy for later use.

2/ Low pressure systems are those subjected to atmospheric pressure only, i.e. vented.

3/ When applicable, ASME Boiler and Pressure Vessel Code, Section VIII may be used.

4/ Refers to fiber reinforced polyester containers

5/ In lieu of interior galvanized, glass-lined or stone-lined tanks.

6/ "Specifications and Recommended Practice for Wood Tanks and Continuous Stove Wood Pipe," publication S-75, National Wood Tank Institute, 848 Eastman Street, Chicago, IL 60622, 197[illegible].

TABLE 3A-8 Examples of Typical Heat Transfer Liquid Properties [6]

Property	Water	Glycols		Silicone Fluid	Hydrocarbons		Glycerine ("Glycerol") 60%/40% Glycerol/water
		50% Ethylene Glycol/Water	50% Propylene Glycol/Water		Aromatics	Paraffinic oil	
Freezing point, °F (°C)	32 (0)	-33 (-36)	-28 (-33)	—	-80 to 15 (-62 to -9)	15 (9)	-31 (-35)
Boiling point, °F (°C) (at atm. pressure)	212 (100)	230 (110) [387 (197) 100% glycol]	225 (106) [370 (180) 100% glycol]	None	358-640 (181-337)	700 (371)	230 (110)
Fluid Stability	Requires pH or inhibitor monitoring	Requires pH or inhibitor monitoring	Requires pH or inhibitor monitoring	Good	Good to Fair	Good to Fair	
Flash Point 2/ °F (°C)	None	None 3/ [232 (111) 100% glycol]	None [210 (99) 100% glycol]	450-600 (232-315)	132-405 (56-207)	300-455 (149-235)	None [350 (177) 99% glycerol]
Specific Heat (73°F, 23°C) [Btu/(lb.°F)]	1.0	0.80	0.85	0.34-0.48	0.36-0.50	0.43-0.63	.80
Thermal Conductivity (100°F, 38°C) [Btu/(hr.ft^2.°F/ft)]	.363 @32°F	.23	.225	.083	.07	.07	.27
Viscosity (csk at 77°F, 25°C)	0.9	3.4	5	20-50	8-50	1-60	7
Toxicity	Depends on inhibitor used	Moderate to high depends on inhibitor used	Slight depends on inhibitor used used	No unequivocal toxic effects are recognized	Moderate	Low	Slight
Lifetime Estimates	Depends on inhibitor used	Less than 2 years	Less than 2 years	More than 5 years	Ranges 1-20 years	On order of 10 years	More than 5 years

1/ These data are extracted from manufacturers literature to illustrate the properties of a few types of liquid that have been used as transfer fluids.

2/ It is important to identify the conditions of tests for measuring flash point. Since the manufacturers literature does not always specify the test, these values may not be directly comparable.

3/ One manufacturer of an inhibited ethylene glycol mixture (50/50 - 60/40 ethylene glycol/water) gives the following data: "Flash point COC ---- NONE
After 50% of initial volume evaporated --- 290°F"

GLOSSARY

Absorptance: The ratio of the amount of radiation absorbed by a surface to the amount of radiation incident upon it (for terrestrial applications, usually calculated for air mass 2 characteristics).

Air chamber: A closed section of pipe or a container filled with air entrapped at atmospheric pressure which when mounted in a water supply line absorbs the pressure surges caused by the rapid opening and closing of valves.

Air gap: An air gap in a potable water distribution system is the unobstructed vertical distance through the free atmosphere between the lowest opening from any pipe or faucet supplying water to a tank, plumbing fixture or other device and the flood level rim of the receptacle. (NSPC)*

Auxiliary energy subsystem: Equipment utilizing energy other than solar both to supplement the output provided by the solar energy system as required by the design conditions and to provide full energy backup requirements during periods when the solar H or DHW systems are inoperable. It may be integrated directly into the solar energy system, or it may be completely separate from it and contain its own means for delivery of heating, cooling and/or hot water to the building.

Backflow: The flow of water or other liquids, mixtures or substances into the distribution pipes of a potable supply of water from any source or sources other than its intended source.

Backflow preventer: A device or means to prevent backflow into the potable water system.

Chemical compatibility: The ability of materials to remain in contact with each other without chemical interaction, such as electrolytic action or plasticizer migration.

Collector, combined: The collector and storage are constructed and operated such that they functionally perform as one unit and the thermal performance of the individual components cannot be meaningfully measured.

Collector, component: Collector that is not thermally integrated with the storage or building. The collector performance can be thermally characterized as an individual component with a moving heat transfer fluid.

Collector efficiency (ASHRAE 93-77): The amount of energy removed by the transfer fluid per unit of gross collector area during the specified time period divided by the total solar radiation incident on the collector per unit area during the same test period, under steady state or quasi-steady state.

Collector subsystem: The assembly used for absorbing solar radiation, converting it into useful thermal energy and transferring the thermal energy to a heat transfer fluid. It includes the entire collector array, with its one or more collector units, together with manifolding and interconnections.

Combustible liquid: Combustible liquid shall mean any liquid having a flash point at or above 100°F (37.8°C) (NFPA 321).

Combustible solids: This term as used herein means cellulosic materials, such as wood, paper and many fibrous materials (except asbestos and some of the synthetic fibers) as defined in Section 5 of the NFPA Fire Protection Handbook, 13th Edition.

Component: An individually distinguishable product that forms part of a more complex product (i.e. subsystem or system).

*National Standard Plumbing Code

Contaminants (hazardous): Materials (solids or liquids or gases) which when added unintentionally (or intentionally) to the potable water supply cause it to be unfit for human or animal consumption. (ASSE 1013)

Control subsystem: The assembly of devices and their electrical, pneumatic or hydraulic auxiliaries used to regulate the processes of collecting, transporting, storing and utilizing energy in response to the thermal, safety and health requirements of the building occupants or building.

Cooling (C) system: The complete assembly of subsystems and components necessary to convert solar energy into thermal energy and use this energy in combination with auxiliary energy, where required, for space cooling purposes. Where cooling is required, nocturnal radiation, evaporative cooling, and/or other means may be used in combination with, or in lieu of, heat actuated space cooling.

Creep: A time-dependent deformation resulting from sustained loads which can be influenced by factors such as temperature and solar radiation.

Design life: The period of time during which an H/C/HW system is expected to perform its intended function without requiring major maintenance or replacement.

Design maximum flow temperature: The maximum temperature that will be obtained in a component when the heat transfer fluid is flowing through the system.

Design maximum no-flow temperature: The maximum temperature that will be obtained in a component when the heat transfer fluid is not flowing through the system.

Dielectric fitting: An insulating or non-conducting fitting used to isolate electrochemically dissimilar materials.

Ease of ignition: The flame exposure time required to produce sustained flaming of a representative specimen of material from a controlled impinging flame source.

Emittance: The ratio of the radiant energy emitted by a body to the energy emitted by a black body at the same temperature.

Energy transport subsystem: Those portions of an H/C/HW system which contain heat transfer fluids and transport energy throughout the system.

Failure (structural): Failure of a structure or any structural element is defined as one of the following:

(a) Sudden, locally-increased curvature, major spalling, or structural collapse.
(b) The inability of the structure to resist a further increase in load.
(c) Structural deflections under design loads that cause significant performance degradation of the component or subsystem.

Flammable liquid: Any liquid having a flash point below 100°F (37.8°C) and having a vapor pressure not exceeding 40 pounds per square inch absolute (2068.6 mm) at 100°F (37.8°C) (NFPA 321).

Flash point: The minimum temperature of a liquid at which sufficient vapor is given off to form an ignitible mixture with the air near the surface of the liquid or within the vessel used as determined by appropriate test procedure and apparatus as specified in NFPA 321.

Flow condition: The condition obtained when the heat transfer fluid is flowing through the collector array under normal conditions.

Heating (H) system: The complete assembly of subsystems and components necessary to convert solar energy into thermal energy and use this energy in combination with auxiliary energy, where required, for heating purposes.

Hot water (HW) system: The complete assembly of subsystems or components necessary to convert solar energy into thermal energy and use this energy in combination with auxiliary energy, where required, to provide hot water in the building. The term hot water as used in this document includes both domestic hot water (DHW) and commercial service hot water (SHW). The commercial service hot water may either be potable or non-potable depending on its intended use.

In-service conditions: The conditions to which a solar H/C/HW system and its components will be exposed during their operational lifetimes.

Load factors: Multipliers by which design loads are increased in order to obtain the loads to be used in ultimate strength design of structural elements.

Manual of Acceptable Practices (MAP): A HUD document providing information and guidance to assist in the use of the MPS.

Maximum service temperature: The maximum temperature at which a system and its components are designed to operate either with or without the flow of heat transfer fluid.

Metastable precipitation: The precipitation of solid matter from a solution under conditions where such precipitation is marginally stable.

Minimum service temperature: The minimum temperature at which a system and its components are designed to operate either with or without the flow of heat transfer fluid.

MPS 4900.1: FHA "Minimum Property Standards for One and Two Family Dwellings."

MPS 4910.1: FHA "Minimum Property Standards for Multifamily Housing."

MPS 4920.1: FHA "Minimum Property Standards for Care-Type Housing."

MPS 4930.2: FHA "Intermediate Property Standards Supplement - Solar Heating and Domestic Hot Water Systems."

"No-flow" condition: That condition obtained when the heat transfer fluid is not flowing through the collector array due to shutdown or malfunction and the collector is exposed to the amount of solar radiation that it would receive under normal operating conditions. Heat transfer fluid may be in the collector but it is not flowing.

Operating energy: The conventional energy required to operate the H/C/HW systems, excluding the auxiliary energy which supplements the solar energy collected by the systems (e.g. the electrical energy required to operate the energy transport and control subsystems).

Outgassing: The emission of gases by materials and components usually during exposure to elevated temperature or reduced pressure.

Pitting: The process by which localized material loss is caused in materials or components by erosion or chemical decomposition.

Physical compatibility: The ability of materials and components in contact with each other to resist degradation by physical actions such as differential thermal expansion.

Plasticizer migration: The movement of plasticizers used in plastic materials. These plasticizers may concentrate in a narrow boundary area or migrate to another material in connection with the specimen.

Potable water: Water free from impurities present in amounts sufficient to cause disease or harmful physiological effects and conforming in its bacteriological and chemical quality to the requirements of the Public Health Service Drinking Water Standards or the regulations of the public health authority having jurisdiction. (BOCA)

Potential heat: The difference between the heat of combustion of a representative specimen of material and the heat of combustion of any residue remaining after exposure to a simulated standard fire, determined by combustion calorimetric techniques.

pphm: Parts per hundred million.

Premature failure: Failure that occurs before the design lifetime.

Rate of heat release: A method of measuring the relative combustibility of materials by determining the rate at which heat is released by the material with calorimetric techniques.

Residual deflection: The portion of the displacement of an element in a structure which is not recovered after the removal of the action causing that displacement.

Safety glazing materials: Glazing materials so constructed, treated or combined with other materials as to minimize the likelihood of cutting and piercing injuries resulting from human contact with these glazing materials.

Service loads: Loads which are expected during the service life of a structure and upon which the design of the structure is based.

Shading angles: Angles that the sun makes in both elevation and azimuth that cause shadows.

Significant (deterioration, loss, etc.): Deterioration that either results in a decrease in performance greater than that allowed for in the design or in the creation of a hazard.

Solar degradation: The process by which exposure to sunlight deteriorates the properties of materials and components.

Solar energy: The photon energy originating from the sun's radiation having a terrestrial wavelength range (air mass 2) from 0.3 to 2.4 micrometers (300-2400 nanometer).

Solar energy system, active: A system which may include collectors, thermal storage, heat transfer fluid and load, and which utilizes solar energy or environmental energy sinks for heating or cooling and in which all energy flows are by forced means (pumps or fans).

Solar energy system, hybrid: A system which may include collectors, thermal storage, heat transfer fluid and load, and which utilizes solar energy or environmental energy sinks for heating and cooling and in which at least one energy flow is by forced means and at least one is by natural means.

Solar energy system, passive: A system which may include collectors, thermal storage, heat transfer fluid and load, and which utilizes solar energy or environmental energy sinks for heating and cooling and in which all energy flows are by natural means (conduction, convection, radiation, or evaporation).

Solar time: The hours of the day as reckoned by the apparent position of the sun. Solar noon is that instant on any day at which time the sun reaches its maximum altitude for that day. Solar time is very rarely the same as local standard time in any locality.

Storage subsystem: The assembly used for storing thermal energy so that it can be used when required.

Subsystem: A major, separable, functional assembly of a system such as complete collector array or storage unit.

System: The complete assembly of subsystems and components necessary to supply heating/cooling and/or hot water to the building.

Tap temperature: The temperature at which hot water is discharged from an outlet at the point of use.

Terminal velocity of hail: The maximum vertical velocity reached by a hailstone, occurring when the drag force on the hailstone is equal to the force exerted by gravity on its mass.

Toxic fluids: Gases or liquids which are poisonous, irritating and/or suffocating, as classified in the Hazardous Substances Act, Code of Federal Regulations, Title 16, Part 1500.

Transmittance: The ratio of the radiant flux transmitted through and emerging from a body to the total flux incident on it.

Ultimate strength design: A method of proportioning structures or members for failure at a specified multiple of working loads and assuming non-linear distribution of flexural stresses.

UV: Ultra-violet radiation, that part of the terrestrial solar energy between 0.3 and 0.4 micrometers (300-400 nanometers).

Vertical penetrations: The vertical passage of a utility chase, pipe, duct, etc., through a fire-rated structural assembly.

Working stress design: A method of proportioning structures or members for prescribed working loads at stresses well below the ultimate and assuming linear distribution of flexural stresses.

Zero hardness: A property of softened water such that no calcium or magnesium can be found in it by ordinary analytical methods.

2 1/2 percent summer design temperature: The outdoor air temperature will be higher than the stated value not more than 73 hours per year (2 1/2% of the 2,928 hours in June through September).

97 1/2 percent winter design temperature: The outdoor air temperature will be lower than the stated values for not more than 54 hours per year (2 1/2% of the 2,160 hours in December, January and February).

ABBREVIATIONS

(Code Groups, Associations, and Gov't. Agencies)

AASHTO	American Association of State Highway and Transportation Officials
AGA	American Gas Association
ANSI	American National Standards Institute
ARI	Air-Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
DOE	Department of Energy
ERDA	Energy Research and Development Administration
FM	Factory Manual
HUD	Department of Housing and Urban Development
NACE	National Association of Corrosion Engineers
NASA	National Aeronautics and Space Administration
NBBPVI	National Board of Boiler and Pressure Vessel Inspectors
NBC of Canada	National Building Code of Canada
NBS	National Bureau of Standards
NESCA	National Environmental Systems Contractor's Association
NEMA	National Electrical Manufacturer's Association
NFPA	National Fire Protection Association
OSHA	Occupational Safety and Health Association
SAE	Society of Automotive Engineers
SMACNA	Sheet Metal and Air-Conditioning Contractor's National Association
UBC	Uniform Building Code
UL	Underwriters Laboratories, Inc.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The interim performance criteria, developed for the Department of Housing and Urban Development, is a baseline document for criteria and standards for the design, development, technical evaluation and procurement of the solar heating and cooling systems to be used in residential buildings during the solar heating and cooling demonstration program authorized by Public Law 93-409, the "Solar Heating and Cooling Demonstration Act of 1974."

This second edition of the "residential criteria" document, represents the first revision to the "Interim Performance Criteria for Solar Heating and Combined Heating/Cooling Systems and Dwellings" published in January 1975. Its revision draws upon comments received and experience gained in the use of two companion documents, the "Interim Performance Criteria for Solar Heating and Cooling Systems in Commercial Buildings," NBSIR 76-1187, and the "HUD Intermediate Minimum Property Standards Supplement, 1977 Edition, Solar Heating and Domestic Hot Water Systems," 4930.2.

These interim criteria are intended primarily for use in the solar residential demonstration program and as a basis for the preparation of definitive performance criteria in accordance with the requirements of Section 8 of PL 93-409.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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